DOCTORAL THESIS

Sensory and Sustainability Challenges in the Consumption of Plant-Based Alternatives: A Focus on Plant-Based Beverages

Helen Vaikma

TALLINNA TEHNIKAÜLIKOOL
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Declaration:
Hereby I declare that this doctoral thesis, my original investigation and achievement, submitted for the doctoral degree at Tallinn University of Technology, has not been previously submitted for doctoral or equivalent academic degree.

Helen Vaikma

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Sensoorika ja jätkusuutlikkusega seotud väljakutsed taimsete alternatiivide tarbimises taimsete jookide näitel

HELEN VAIKMA

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List of publications

The list of the author's publications, on the basis of which the thesis has been prepared, is as follows (copies of the full articles are in Appendices 1–4):

I **Vaikma, H.,** Kaleda, A., Rosend, J., & Rosenvald, S. (2021). Market mapping of plant-based milk alternatives by using sensory (RATA) and GC analysis. Future Foods, 4, 100049. https://doi.org/10.1016/j.fufo.2021.100049 (ETIS 1.1)

II **Vaikma, H.**, Metsoja, G., Bljahhina, A., & Rosenvald, S. (2022). Individual differences in sensitivity to bitterness focusing on oat and pea preparations. Future Foods, 6, 100206. https://doi.org/10.1016/j.fufo.2022.100206 (ETIS 1.1)

III **Vaikma, H.** (2025). Unveiling the mindset: measuring consumer perception towards the dimensions of sustainability. Sustainable Futures, 9, 100616. https://doi.org/10.1016/j.sftr.2025.100616 (ETIS 1.1)

IV **Vaikma, H**., Almli, V. L., Harwood, W., Kern, M. (2025). Consumer perceptions of sustainability towards ingredients, packaging, labelling, and storage conditions in milk, burger products, and plant-based alternatives: A study in Sweden and Italy. Future Foods, 11, 100635. https://doi.org/10.1016/j.fufo.2025.100635 (ETIS 1.1)

Other publications and conferences related to the author's doctoral topic, but not the primary focus in the given thesis:

V **Vaikma, H**.*, Kaleda, A., Rosend, J., Rosenvald, S. (2020). What would you want for a drink? Sensory mapping of plant-based milk alternatives. Poster presentation at EUROSENSE 2020: 9th European Conference on Sensory and Consumer Research, 14.12.2020. (ETIS 5.2)

VI **Vaikma, H.;** Rosenvald, S.*; Rosend, J.; Kaleda, A. (2021) Plant Based Milk Alternatives - What Makes Them "Milky". Book of abstracts FoodBalt 2021: 14th Baltic Conference on Food Science. 15.03.2021. (ETIS 5.2)

VII **Vaikma, H.**; Metsoja, G.; Rosenvald, S*. (2021). Plant based proteins - Bitter or not bitter? Oral presentation at 18th Nordic Sensory Workshop. 27.04.2021. (ETIS 5.2)

VIII Harrik, A., **Vaikma, H**. (2021). Eesti taimsete piimajookide turg kasvab, aga on veel ühekülgne [The Estonian market for plant-based milk bevearges is growing, but still one-sided]. https://novaator.err.ee/1608331661/eesti-taimsete-piimajookide-turg-kasvab-aga-on-veel-uhekulgne, 08.09.2021. (ETIS 6.3)

IX **Vaikma, H.** (2022). Sustainability and Consumer Behaviour: Literature Review [Literature Review]. Tallinn: European Sensory Network. Retrieved from European Sensory Network website: https://esn-network.com/fileadmin/user_upload/documents/2022/ESN_Sustainability_Consumer_Behaviour_Literature_Review_Publish_06Dec22.pdf (06.12.22) (ETIS 6.7)

X Metsoja, G., **Vaikma, H.**, Rosenvald, S.* (2022). Plant based proteins - Bitter or not bitter? Oral presentation at EUROSENSE 2022: 10th European Conference on Sensory and Consumer Research, 13 - 16 September 2022, Turku, Finland. (ETIS 5.2)

XI **Vaikma, H**.*, Rosenvald, S., Dreyfuss, L., Valerie, A., Harwood, W., McEwan, J. A. (2022). Development of a sustainability dimensions questionnaire. Oral presentation at EUROSENSE 2022: 10th European Conference on Sensory and Consumer Research, 13 - 16 September 2022, Turku, Finland. (ETIS 5.2)

XII **Vaikma, H**. (2023). Mapping the Market: An Overview of Plant-Based Beverages' Sensory Attributes. Speciality Coffee Association, 25 (19), 02.05.2023. (ETIS 6.3)

XIII **Vaikma, H**.*, Kern, M., Tvardik, N., Rosenvald, S., Dreyfuss, L., Almli, V., Harwood, W., McEwan, J. A. (2023). How is sustainability perceived in the context of plant-based alternatives? Poster presentation at Pangborn 2023: 15th Pangborn Sensory Science Symposium, Nantes, France, 20 - 24 August 2023. (ETIS 5.2)

XIV **Vaikma, H.,** Maasikmets, M., Kuldjärv, R., Kutti, M.-L., Rosenvald, S., Straumite, E., Stulova, I. (2025). Sensory perception and preferences of oat-based vanilla-flavoured frozen desserts among children (aged 8–16) and adults. Food Quality and Preference, 129, 105533. https://doi.org/10.1016/j.foodqual.2025.105533 (ETIS 1.1)

* Presenting at the conference

Author's contribution to the publications

Contribution to the papers in this thesis are:

I **Main** author of Article I. The author conceptualised this research together with her supervisor Sirli Rosenvald. The main author also developed the methodology for sensory analyses, analysed the data, interpreted the results and mainly wrote the manuscript.

II **Main** author of Article II. The author conceptualised this research together with her co-authors Sirli Rosenvald and Grete Metsoja. Data analyses, interpretation and writing were done together with Grete Metsoja.

III **Sole** author of Article III. The author conceptualised this research and developed the research design. All data analyses and interpretations were performed by her.

IV **Main** author of Article IV. The author conceptualised this research and developed the research design. She led an international team of academics and professionals and distributed the tasks among its members. She analysed and interpreted the data together with her colleagues, as well as mainly wrote the manuscript.

Introduction

Context of the study

The demand for plant-based (PB) alternative products is rapidly increasing, driven by consumers' concerns about various sustainability issues such as health/well-being, the environment, and ethics (Fehér et al., 2020; Graça et al., 2019; Haas et al., 2019; Pointke, Ohlau, et al., 2022). One of the largest PB alternative groups is PB dairy alternatives, which are seen as one of the dominant food trends in the dairy industry today (Euromonitor International, 2019). Although PB dairy alternatives already exist in some food cultures – such as stinky tofu (chòu dòufu, which is a cheese-like fermented soy curd) (Liu, Han, & Zhou, 2011), soy beverages in China, horchata (tigernut beverage) in Spain (Mäkinen et al., 2016), and oat flummery (yoghurt-like semi-liquid fermented oat dessert) in Estonia (Sõukand et al., 2015) – the PB dairy alternative sector is undergoing rapid innovation and expansion. PB dairy alternative market is estimated to increase at a compound annual growth rate (CAGR) of 10.97% from 2025 to 2030 (Mordor Intelligence, 2025). Within this sector, the largest category by sales are PB milk alternatives, with a value of €2.2 billion in 2022 in Europe (Austria, Belgium, Denmark, France, Germany, Italy, Netherlands, Poland, Portugal, Romania, Spain, Sweden, UK) (GFI Europe, 2022) and $2.5 billion in 2020 in the US (Plant Based Foods Association, 2021). Therefore, this study focuses (Figure 1) on PB milk alternatives (PB beverages), which represent the largest category within PB products, to explore the complexity inherent in PB alternatives.

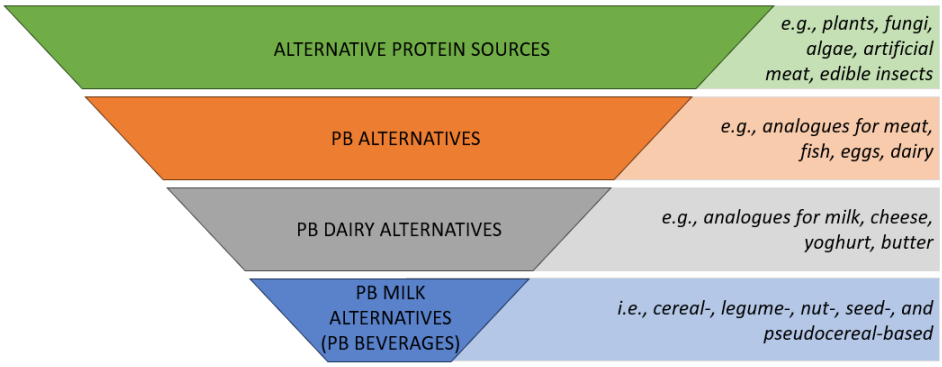

Figure 1. Research funnel from overall study context to focus on plant-based (PB) beverages. Compiled by the author, based on the review papers by Appiani et al., 2023; Lima et al., 2022; Sethi et al., 2016.

PB milk alternatives are typically produced by liquid extraction from ground raw material (Silva et al., 2020; Yadav et al., 2017). These plant extracts are often made to replace milk products. Furthermore, the term 'PB dairy alternatives' refers more broadly to PB products that mimic various dairy items and may involve additional processing steps, such as fermentation for producing PB cheese or yoghurt alternatives (Harper et al., 2022). However, regulatory restrictions influence the terminology used. The Court of Justice of the European Union (2017) prohibits the designation of PB products as 'milk' products since milk is solely a mammary secretion according to EU regulations (No 1308/2013; Official Journal of the European Union, 2013). Due to the current legislations, PB milk alternatives are hereby referred to as PB beverages (Figure 1).

As noted earlier, PB products are often seen as a major opportunity to make the current food system more sustainable (Alae-Carew et al., 2022; Carlsson Kanyama et al., 2021; Craig et al., 2023; Kozicka et al., 2023), aligning with consumer motivations for choosing PB products (Fehér et al., 2020; Graça et al., 2019; Haas et al., 2019; Pointke, Ohlau, et al., 2022). Sustainability is defined as meeting present needs without compromising future generations' ability to meet theirs (Brundtland, 1987). In this study, sustainability involves four dimensions in the PB context: health (e.g., fulfilling dietary and nutritional needs), environment (e.g., minimizing harm such as greenhouse gas emissions), social (e.g., promoting fairness like food security), and economic (e.g., ensuring affordability). However, many consumers remain sceptical or unaware of PB alternatives' sustainability potential (Ford et al., 2023; Hartmann & Siegrist, 2017) and may view them as less sustainable, citing concerns like extensive processing affecting health and environment (Aschemann-Witzel et al., 2021; Varela et al., 2022). These concerns are valid, as plant-based alternatives are not inherently sustainable and often benefit from a perceived 'sustainability halo effect' (Macdiarmid, 2022). Additional barriers, such as sensory shortcomings (e.g., bitterness in taste, graininess, and instability in texture) (McClements & Grossmann, 2021), further challenge their market acceptance. These challenges span both sensory and non-sensory aspects (Adamczyk et al., 2022; Giacalone et al., 2022; Jahn et al., 2021), or more broadly, food-internal and food-external aspects (Eertmans et al., 2001).

Research problem and research gaps

Rising consumer interest emphasises the importance of tackling the adoption barriers and enhancing product quality, highlighting the ongoing need for research and development in the PB alternatives industry (Tachie et al., 2023). The **research problem** relates to the finding that many consumers are unable to choose PB beverages, despite the great sustainability potential (Aschemann-Witzel et al., 2021; Ford et al., 2023; Hartmann & Siegrist, 2017; Malek & Umberger, 2023; Varela et al., 2022). Although there are different products with various ingredients and production methods available on the market (assuming everyone can find something they'd enjoy), the conflict between finding a balance between potential sustainability and sensory acceptability makes the issue even more complex. Thus, it seems like a constant argument between the two sides – non-sensory and sensory (Giacalone et al., 2022).

The problem is investigated by considering various research gaps (RG). It is important to reflect both food-internal and food-external properties in research as their interrelationships can shape food pleasantness as well as consumption behaviour (Eertmans et al., 2001). Despite this, studies that investigate intrinsic and extrinsic together are rather limited, highlighting a need for a more holistic approach, as noted in a review paper on food product attributes in consumer and sensory research (Symmank, 2019). Giacalone et al. (2022) further confirm that current studies investigate the sensory (food-internal) and non-sensory (food-external) determinants of PB food and beverage consumption separately, rather than as a holistic phenomenon (**RG1**). It is essential to move beyond focusing on a single aspect and instead examine how multiple factors collectively influence consumption, to gain a comprehensive understanding of real food choices (Giacalone et al., 2022; Symmank, 2019). The current thesis looks at both aspects to explore consumer perception of PB alternatives further.

Theme A: Sensory (food-internal). Existing publications on the flavour characteristics of PB raw materials and their impact on PB dairy alternative products are sparse (Amyoony et al., 2023). Hence, there is a gap in the understanding of the emergence of specific sensory nuances from the PB beverage perspective (**RG2**). Given that numerous studies highlight taste as the most critical factor influencing food choice decisions (Hebden et al., 2015; Mäkinen et al., 2016; Mekanna et al., 2024), it is important to understand flavour characteristics in the development of PB foods and beverages.

Numerous studies have investigated consumer perceptions of PB alternatives, given the current relevance of the topic. A systematic review of consumer perceptions of PB beverages published since 2019 shows that the number of publications has tripled between 2022 and 2023 (Mekanna et al., 2024). However, another review on the sensory properties and consumer acceptance of PB alternatives (including meat, dairy, fish, and eggs) highlights the limited research on how socio-demographic variables within consumer segments influence sensory perceptions (Appiani et al., 2023). For instance, how diet habits influence bitterness perception and food preference (Pagliarini et al., 2021). One of the most problematic sensory shortcomings of PB alternatives is bitterness, which influences acceptability (McClements & Grossmann, 2021; Moss et al., 2022). This is challenging as consumer sensitivity to taste varies due to molecular differences in taste compounds, physiological variations among individuals, and differing levels of exposure to certain tastants. Addressing the gap in identifying consumer segments in the bitterness perception (**RG3**) needs to be addressed in order to overcome barriers to PB alternative consumption (Appiani et al., 2023). It emphasizes the need to explore these factors, as a 'one size fits all' approach is unlikely to satisfy all consumer expectations of PB foods and beverages (Giacalone et al., 2022). Thus, consumer segmentation mentioned in RG3 was not only limited to the sensory aspect (food-internal) but was later extended to perceptual sustainability (food-external) research.

Theme B: Sustainability (food-external). Consumer research in sustainability is predominantly environment-oriented (Bangsa & Schlegelmilch, 2020; Sesini et al., 2020). Often they do not consider sustainability as a holistic combination of different dimensions (Camilleri et al., 2023), but only include one dimension (**RG4**). This narrow perspective hinders generalisation, making it difficult to integrate sustainability dimensions into managerial strategies, achieve a balance among sustainability objectives, and effectively guide consumer decisions (Camilleri et al., 2023).

Further, consumer perception of PB beverages is relatively underexplored (Adamczyk et al., 2022). Available studies that do exist use different approaches leading to limited consistency and comparability (Fischer et al., 2023). While there is some research on the motivators and barriers to PB alternative consumption, studies specifically examining sustainability perceptions in the context of PB alternatives remain limited (**RG5**) to the best of the author's knowledge. Future research should investigate how extrinsic properties, such as sustainability influence the acceptability of PB alternatives (Moss et al., 2022), essential for developing PB alternative products that meet consumer needs and expectations.

Aim and research questions

This study **aims** to explore the most prevalent food-internal (i.e. sensory as theme A) and food-external (i.e. sustainability as theme B) factors influencing the consumption of PB beverages as an example of PB alternatives. As noted above, current studies investigate food-internal/external factors associated with PB consumption rather separately

(Giacalone et al., 2022), although both should be considered as they shape consumer behaviour together (Eertmans et al., 2001). Overall, this research is divided into two parts: the first part focuses on understanding sensory perception at the compound level (sensory science), while the second part investigates sustainability perception in a four-dimensional manner (consumer science). However, both aspects are related to the consumer perspective on PB beverages. Four research questions (RQ) were formulated:

Theme A: Sensory (food-internal)

RQ1 What is the current market situation of PB beverages in terms of sensory aspects?

RQ2 How is the bitterness of PB substances, prevalent in PB beverages, perceived by different consumers?

Theme B: Sustainability (food-external)

RQ3 How do different consumer segments perceive sustainability across various dimensions?

RQ4 How is sustainability perceived in the context of PB beverages?

This doctoral thesis consists of four publications in total (see List of Publications). The framework of the thesis and the interrelationships between articles can be seen in Figure 2. Based on the tripartite model of attitude, the thesis further emphasises the affective (taste) and cognitive (sustainability) aspects as key influencers of PB alternative (incl. PB beverage) consumption behaviour. As this is a multidisciplinary study, Articles I and II focus on the sensory perception of PB alternatives in the field of food technology (sensory science), while Articles III and IV focus on sustainability perception in the field of marketing (consumer science). Tackling key issues in both fields could help increase consumers' positive attitudes toward plant-based alternatives, which in turn is likely to increase consumption behaviour.

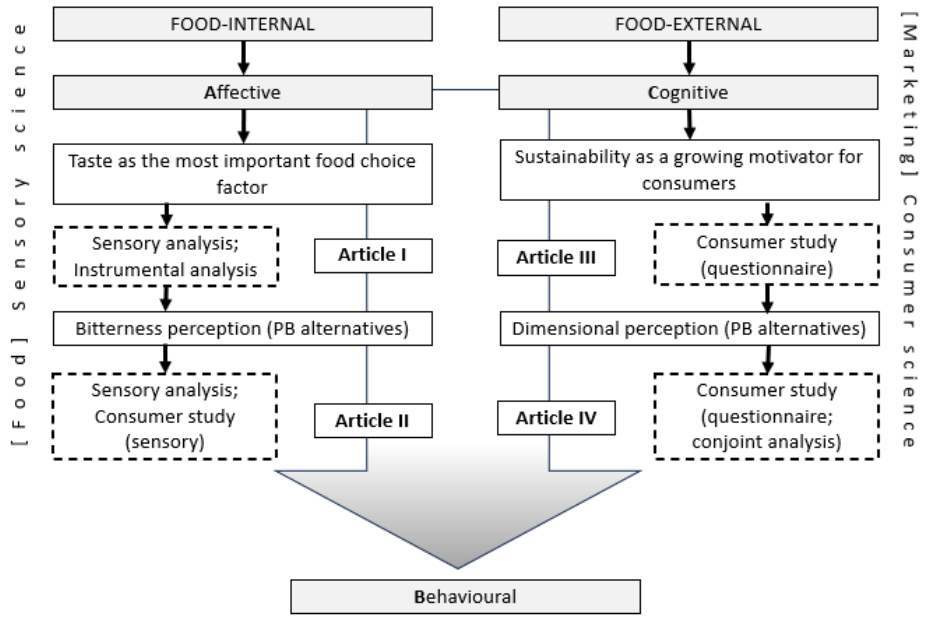

Figure 2. The framework of the thesis. Compiled by the author.

Article I (ETIS 1.1) addressed RQ1 by examining the sensory profile of 90 PB beverages available on the Estonian market as of January 2020. Quantitative data was collected on various appearance, odour, taste, and texture characteristics using a trained sensory panel (n = 10). In addition, an aroma analysis was performed instrumentally using GC/MS/O to identify the key compounds and correlated with the sensory data to clarify the impact of the compounds on the sensory profile. This paper also served as an introduction to RQ2, as Article I discussed product bitterness (among other off-flavours) and possible technological causes. The preliminary results of this study were presented at the 9th European Conference on Sensory and Consumer Research 'EUROSENSE 2020' in December 2020. In response to heightened interest after publishing, the findings were also featured in popular science publications by ERR Novaator (Article VIII) and Speciality Coffee Association (Article XII), see List of Publications.

Article II (ETIS 1.1) provided an investigation for RQ2 by focusing bitterness perception of consumers. The study used a trained sensory evaluation panel (n = 12) to investigate the perception of bitterness of various compounds associated with PB substances, prevalent in PB beverages, as well as commonly used bitter standards. A similar test was conducted on selected samples with untrained consumers (n = 100) to provide a larger scale for understanding bitterness perception of PB substances and to investigate whether bitterness perception is influenced by dietary habits. The data was collected between October 2021 and April 2022. The findings of this paper were presented at the 10th European Conference on Sensory and Consumer Research 'EUROSENSE 2022' in September 2022.

Article III (ETIS 1.1) related to RQ3 by examining how different consumer segments perceive sustainability across different dimensions. A novel scale was developed to measure perceptions of sustainability in four dimensions: environmental, social, economic, and health. Two online consumer studies were conducted between April 2022 and October 2022. Study 1 (n = 1019 including Estonia, Italy, Sweden, and France) involved the development of a factor model for the questionnaire, while Study 2 (n = 926 including Sweden and Italy) not only confirmed the factorial model but also identified five distinct consumer segments. The preliminary results were presented at the 10th European Conference on Sensory and Consumer Research 'EUROSENSE 2022' in September 2022.

Article IV (ETIS 1.1) addressed the perception of sustainability multidimensionally similar to Article III (RQ3) but also compared how the perception varies in the context of PB alternatives, such as PB beverages (RQ4). An online consumer study (n = 600 including Italy and France) was conducted in October 2022, which included a questionnaire (developed in Article III) and a Choice-Based Conjoint study. The conjoint study enabled to compare which of the four dimensions of sustainability are linked to the perception of specific product attributes, such as raw materials, packaging, level of processing and labelling. The findings of this study were also presented at the 15th Sensory Science Symposium 'Pangborn 2023' in August 2023.

Contributions

The thesis made a **theoretical contribution** by developing multiple conceptual models. First, the Plant-Based Alternative Purchase Perception Matrix as an extension of the Green Purchase Perception Matrix by Peattie (2001). It integrated the main food-internal and food-external factors conflicting in the consumption of PB alternatives, while also integrating food (sensory science) and marketing (consumer science) fields. Combined with the Customer Value Theory, there is a constant trade-off between the values associated

with confidence and compromise. Secondly, the term sustainability was redefined withing the context of PB alternatives. For this, the well-known three-dimensional (i.e. social, environmental, economic) sustainability concept was extended to a four-dimensional concept with an additional health dimension (Article III). This provided additional input for discussions in previous publications on how sustainability perception can vary individually (Articles III, IV) and depend on product characteristics (Article IV). Thus, it emphasised the importance of a multidimensional approach to sustainability rather than a generalised one. Lastly, this study enhanced the theoretical understanding of the food-internal aspects of PB alternatives by identifying key sensory attributes (Article I) and further exploring bitterness (Article II). It also challenged current bitterness standards, highlighting the complexity of bitterness perception at molecular and individual levels (Article II).

As an **empirical contribution**, this study quantified key volatile compounds affecting the odour and taste profile of PB beverages (Article I) and further compared the bitterness perception of selected PB raw materials overall and within diet groups (Article II). Understanding the technological factors influencing sensory profiles is crucial to improving the acceptability of PB alternatives. From a sustainability perspective, the empirical findings offered insights to the multidimensional nature of consumer perceptions (Article III, IV). In addition, there were some distinctive differences in perception between socio-demographical groups (Articles II, III, IV).

This study provided **methodological contributions** for both sensory and consumer research. For sensory analysis, a comprehensive list of sensory terms for PB beverages was created (Article I) that can be utilised in other PB alternative sensory studies. Additionally, Article I examined the Rate-All-That-Apply (RATA) method for sensory market mapping purposes, confirming its effectiveness and suitability for analysing an extensive number of samples. To explore sustainability perception, Article III developed and validated a novel four-dimensional Sustainability Dimensions Perception Scale (SDPS), which was also used in Article IV, offering a useful tool for any future research.

The **practical contribution** highlights the need for food developers to be more consumer-driven during product development. It is important to know how their production processes can impact sensory profile though some specific volatile (Article I) and bitter (Article II) compounds. As Reipurth et al. (2019) noted, improving the taste of PB foods could enhance their consumption. Bitterness greatly affects product acceptance, and perceptions of bitterness vary widely for both consumers and trained assessors (Article II). Therefore, it is important to know your target audience. Moreover, since sustainability perception varies across consumer groups (Article III, IV) and product characteristics (Article IV), these differences should also be considered for both educational and marketing purposes to encourage consumers to make conscious, sustainable decisions. As Haas et al. (2019) pointed out when comparing cow milk and PB beverages – understanding consumer views on sustainability impact of food can help to create better products and communication strategies. Additionally, the SDPS developed specifically for this purpose (Article III) can aid policymakers and organisations in easily identifying areas where consumer education is needed.

*

The **current thesis** comprises a cover paper and four articles. Chapter 1 is an overview of the theoretical framework. Chapter 2 explains the methodological choices by providing an overview of the research design. Chapter 3 details the main research findings, which are discussed in relation to existing literature. Chapter 4 presents the conclusions, along with a discussion of implications, limitations, and opportunities for future research.

Abbreviations

PB	plant-based (i.e. made from plant ingredients)
AB	animal-based (i.e. contains ingredients of animal origin)
SDPS	Sustainability Dimensions Perception Scale
RATA	Rate-All-That-Apply (method)
PCA	Principal Component Analysis (method)
PLSR	Partial Least Squares Regression (method)
CFA	Confirmatory Factor Analysis (method)
EFA	Exploratory Factor Analysis (method)
GC/MS/O	Gas Chromatography/Mass Spectrometry/Olfactometry (instrument, method)

Explanations of abbreviations used in the thesis – the table.

1 Theoretical framework

1.1 Consumer attitudes towards plant-based alternatives

The current study is investigating PB alternatives based on a tripartite model of attitudes (or ABC model of attitudes), which is a combination of affective, cognitive and conative responses (Rosenberg & Hovland, 1960 as cited in Bagozzi et al., 1979; Fabrigar et al., 2005; Kaiser & Wilson, 2019; Mustaffa et al., 2020; Pratkanis et al., 1989). Conation is also often referred to as a measure of behavioural intention (Bagozzi et al., 1979). Furthermore, the current study adopted a hierarchical version of the model based on Ajzen (2005), where attitudes influence behaviour, but overall attitude is affected by a combination of affective and cognitive components (Figure 3). Further, affective and cognitive elements are often highly correlated. Hence, the behavioural component will not be focused separately in this study, as it can be the outcome of the previous two.

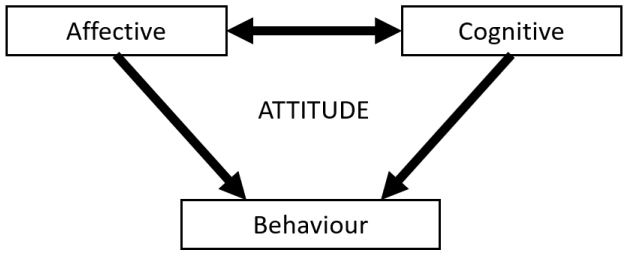

Figure 3. Tripartite model of attitudes. Compiled by the author, adapted from Ajzen, 2005; Brock et al., 2022; Jain, 2014; Rosenberg & Hovland, 1960 as cited in Bagozzi et al., 1979.

In the context of the present study, the affective component is considered as the trigger of sensory stimulation. For example, more attractive products (e.g. visually appealing, tasting pleasant) may prompt a behaviour (Vandenbroele et al., 2020). Cognitively, consumer interest in sustainability issues and problem-solving methods (Piligrimienė et al., 2020), as well as knowledge through visual cues such as sustainability labels (Vandenbroele et al., 2020), can shape consumers' thoughts about their food choices. The behavioural component reflects consumers' efforts to engage in sustainable behaviour (Piligrimienė et al., 2020). Although this does not automatically imply that PB alternatives are always the sustainable choice (as sustainability is a complex, multidimensional issue), PB alternatives still represent a potential approach to consuming more sustainable products (Ford et al., 2023; Hartmann & Siegrist, 2017). While affective and cognitive aspects influence behavioural intentions through attitudes, it is also important to encourage consumers to make these sustainable choices by making sustainable behaviour more convenient, accessible (Vandenbroele et al., 2020) and tasty.

Consumer behaviour is often investigated through internal and external factors, e.g. studies about impulse buying online (Kimiagari & Asadi Malafe, 2021), sustainable consumption (Piligrimienė et al., 2020), and information avoidance (Song et al., 2021). These publications address internal processes (e.g. perception, attitude, knowledge) and external forces (e.g. social norms, regulations, prices) from the consumer perspective. Recent work on food choice, however, has also examined these factors from a food perspective, distinguishing between food-internal and food-external stimuli (P.-J. Chen & Antonelli, 2020; Olmedo et al., 2021). Such an approach is based on a model developed by Eertmans et al. (2001), which considers food-internal factors as sensory-affective

responses (e.g. colour, odour, taste) and food-external factors as a combination of non-food aspects (e.g. information, social environment, accessibility). The PB alternatives are therefore addressed in the given dissertation based on the Eertmans et al. (2001) model. The following subchapters will discuss the food-external and food-internal aspects, focusing on chosen factors as the most common considerations for PB alternatives.

1.1.1 Taste as the common food-internal factor for plant-based alternatives

In terms of food-internal factors, many studies over the years have shown that taste is the most important attribute driving the food choice decision (Combris et al., 2009; Dalton et al., 1986; Hebden et al., 2015; Mäkinen et al., 2016; Malone & Lusk, 2017; Mekanna et al., 2024), which in the current study linked to the affective aspect influencing the attitude. Even when consumers had to choose between a safer (incl. healthier) and tastier product, the taste was still more important (Combris et al., 2009; Malone & Lusk, 2017). Currently, there are five widely recognized taste modalities (the so-called basic tastes): salty, sweet, sour, bitter, and umami. However, there has been a discussion about the mechanisms underlying other tastes that may be considered additional taste modalities, such as fat (Calvo & Egan, 2015; Iwata et al., 2014; Spaggiari et al., 2020), carbonation (Chandrashekar et al., 2009; Spaggiari et al., 2020) and calcium (Iwata et al., 2014; Tordoff et al., 2012). In addition, odour plays an important role in influencing perceived taste, as odorants are released in the retronasal cavity (Pu et al., 2022) and can influence the intensity of taste modalities as well as bring out other taste nuances (Small & Prescott, 2005). Taste perception is a combination of both physiological taste mechanisms and taste characteristics associated with past odour memories (Miranda, 2012; Small & Prescott, 2005). As the perception of taste is a deeply personal experience and at the same time the most important factor in food choices, it is a key challenge for food producers.

The development of taste preferences is a complex process. Food taste preferences start developing already *in utero* as foetuses can perceive flavours in amniotic fluid through their gustatory and olfactory systems (Birch, 1999; Ustun et al., 2022; Ventura & Worobey, 2013). The development of food preferences continues during childhood and is an essential part of distinguishing between nutritious and toxic foods (Birch, 1999; Wardle & Cooke, 2008). Due to the evolutionary preference for energy-rich products, sweet, salty and fatty products are often more appealing, and their easy availability in today's market also often leads to unhealthy choices (Beauchamp, 2016; Birch, 1999; Breslin, 2013; Brondel et al., 2022), whereas other 'new' foods can be easily rejected due to food neophobia (Birch, 1999; Su, Zhang, et al., 2024). On the other hand, some taste modalities act as indicators of potential negative consequences, such as sourness indicating unripeness (Breslin, 2013; Frank et al., 2022) or bitterness indicating toxicity (Breslin, 2013; Jalševac et al., 2022; Spaggiari et al., 2020). It is known that the development of food preferences is a combination of environmental (e.g. exposure) and genetic influences (Birch, 1999; Wardle & Cooke, 2008), although, with ageing, environmental determinants become more important than genetic (Navarro-Allende et al., 2008).

Despite the growing interest in PB alternatives, currently available products often have their sensory shortcomings. One of the most common problems is related to bitterness (McClements & Grossmann, 2021; Part et al., 2023; Tangyu et al., 2019) or off-flavours in the specific plant-based material (Part et al., 2023; Sethi et al., 2016), but also textural issues like graininess (Dobara et al., 2016; McClements, 2020) and unstableness (McClements & Grossmann, 2021; Sethi et al., 2016). The attention to

developing PB beverages is currently aimed at the elimination of off-flavours as well as increasing stability and shelf-life (Paul et al., 2019). Furthermore, consumers who have previously had unpleasant experiences with PB alternatives need to move beyond their negative associations to give these products another chance and potentially replace those negative views with positive ones (Schouteten et al., 2016).

1.1.2 Sustainability as the common food-external factor for plant-based alternatives

Etymologically, the word 'sustainability' comes from the Latin word *sustinēre* which means 'to maintain' (Caradonna, 2014). One of the most cited definitions of sustainability is from a report 'Our Common Future' by the Brundtland Commission (formed by the UN), which formulates sustainability as 'development that meets the needs of the present without compromising the ability of future generations to meet their own needs' (Brundtland, 1987). Generally, it can be said that sustainability is about maintaining the quality of life (Hedlund-de Witt, 2014; Mella & Gazzola, 2015; Uren et al., 2019). However, it is often criticised that 'sustainability' as a term lacks unified conceptualisation since it depends on various interpretations of what will be sustained (Hedlund-de Witt, 2014; Sneddon et al., 2006). The term 'sustainability' will be redefined in relation to PB alternatives in Chapter 1.2.2, which addresses specific sustainability issues in detail. In contrast, the current chapter provides only a general overview of sustainability in relation to PB alternatives.

Food-external factors influencing PB alternative consumption are mostly linked to various sustainability concerns, which relate to the cognitive aspect influencing the attitude. A review about following PB diets and reducing meat consumption confirmed that health, environment and ethics are the main motivators that increase the consumption of PB products (Fehér et al., 2020; Graça et al., 2019; Haas et al., 2019; Pointke, Ohlau, et al., 2022). The importance of these aspects of PB foods may also vary by consumer. For example, younger consumers tend to shift to vegetarianism due to moral and environmental reasons, whereas older vegetarians (aged 41–60) choose this more due to health reasons (Pribis et al., 2010).

While sustainability is a crucial factor in promoting PB alternative consumption, various sustainability shortcomings (as discussed in 1.2.2) may affect the overall sustainability of PB alternatives. Additionally, there may be even more barriers involved in choosing PB alternatives. Drawing on the Theory of Planned Behaviour (TPB) (Ajzen, 1985), sustainable decisions (behaviour) are driven by a combination of attitudes towards the behaviour, subjective norms and perceived behavioural control. First, as an example of perceived behavioural control, the accessibility of PB alternatives can be challenging. ProVeg International (2020) carried out a survey with European consumers (n = 6221) of which 76% were following a PB diet and 24% were reducers of animal-based products. The study concluded that 40% of them wish to have a bigger PB beverage selection in stores. Poor accessibility of PB products is an important issue since supermarkets play a role in shaping consumers' consumption of PB proteins (Gravely & Fraser, 2018). This also includes pricing as PB alternatives tend to be expensive (Macdiarmid, 2022; ProVeg International, 2020) and can reduce willingness to pay (Szenderák et al., 2022). Secondly, as an example of subjective norms, the consumption of animal-based products is often linked to social aspects, such as social status (Stoll-Kleemann & Schmidt, 2017), masculinity (Mycek, 2018) or stigmatisation of vegetarianism (Aschemann-Witzel et al., 2021). Thus, consumers may feel socially excluded by preferring PB alternatives (Macdiarmid,

2022). Thirdly, as an example of attitude towards consumption of PB alternatives, PB alternatives are generally a novel product category for many. Unfamiliar foods can induce scepticism – a phenomenon known as 'food neophobia' (Jaeger & Giacalone, 2021; Pasqualone, 2022). Novelty sometimes also comes with a preconception that PB foods are more difficult to prepare (Macdiarmid, 2022; Pohjolainen et al., 2015).

The importance of these various barriers depends on the consumer. Faria & Kang (2022) discussed in their study that if consumer's food consumption is strongly affected by their surrounding food culture, they are less willing to try novel foods. However, if this consumer is driven by different sustainability values, they are often less affected by it. After all, dairy avoidance is often linked to consumer beliefs and attitudes (Allen, Goddard, Farmer, 2018).

1.2 Purchase perception matrix for plant-based alternatives

In this given research, PB alternatives are addressed through two key factors: degree of confidence and degree of compromise. This is based on a publication by Peattie (2001), which described a Green Purchase Perception Matrix and provided specific examples. In terms of 'Win-Win' purchases, consumers are confident that the product will benefit the environment and they also feel that they must compromise less on their preferences or habits. For example, recycled paper products use materials that otherwise would go to waste but are generally easy to access and use. When it comes to 'Why bother?' purchases, consumers are not convinced if the product is making a difference (low degree of confidence) and purchasing involves some kind of trade-off (high degree of compromise). For example, many people are sceptical that electric cars are more environmentally friendly and feel that they come with some inconveniences, such as being expensive and requiring charging stations. 'Why not?' purchases require less compromising but do not offer a definite environmental benefit. For instance, biofuels are becoming readily available at petrol stations, but there is much debate about whether this has any environmental value. On the contrary, 'Feelgood' purchases also give a high level of confidence but require more trade-offs, such as buying organic products that are only available in a specific shop and not in regular grocery.

Customer Value Theory (CVT) (Sweeney & Soutar, 2001; Woodruff, 1997; Zeithaml, 1988) explains that consumers' purchasing behaviour depends, on the one hand, what they want and perceive receiving from the product, and on the other hand, on what they are willing to give for the product. Therefore, there is always a trade-off between the perceived benefits and the costs involved, with both factors differing from person to person. Zeithaml (1988) illustrates that some consumers want volume, while others value quality; similarly, some are willing to spend more money, whereas others are willing to invest more time. Ng et al. (2024), in the context of green consumption, further develop CVT and suggest that perceived values consist of cognitive and affective aspects, including functional value (practical benefits), relational value (interactions with companies and other consumers), emotional value (pleasure and fulfilment), and perceived green product value (product properties and design aimed at minimising environmental costs and promoting environmentally friendly behaviour). Regarding the Green Purchase Matrix, it can be proposed that a high degree of confidence contributes to what the consumer receives, whereas a high degree of compromise is likely driven by what the consumer is willing to give.

In the given study context, the development of PB alternatives faces a complex issue. On the one hand, there is a great interest in such products due to food-external stimuli,

such as sustainability. Sustainability is one of the most important factors for the consumption of PB alternatives (further discussed in Chapter 1.2.2), and within the context of CVT, these products can provide sustainable product value (although not always). On the other hand, specific PB raw materials often have their food-internal issues, such as bitterness. Taste is one of the main concerns for PB alternatives available on the market (further discussed in Chapter 1.2.1), and within the context of CVT, compromises in taste may reduce the emotional value (pleasure) of the PB product.

Complementing the previous, Green Purchase Perception Matrix by Peattie (2001) can be reinterpreted in a PB context as the Plant-Based Alternative Consumer Perception Matrix (Figure 4). Sustainability, the food-external factor, is seen as the main contributor to the degree of confidence. Bitter taste, the food-internal factor, is considered to contribute to the degree of compromise. 'Win-win' would be the goal product that is both highly sustainable and without any off-tastes. To encourage consumers to choose PB alternatives, food producers should pay attention to both sides of the equation. This seems to be the main issue with PB alternatives available on the market today. For example, 'Why bother?' products (such as PB burger and cheese alternatives) that have been developed to mimic the sensory properties of the conventional animal-based (AB) version of these products, although PB materials normally behave very differently (Moss et al., 2023; Wickramasinghe et al., 2021). This also means that these products tend to be highly processed, which makes consumers sceptic about the health sustainability of the products (Giacalone et al., 2022; Granato & Wassmann, 2024; Macdiarmid, 2022; McClements, 2023). Ultra-processing further suggests that other important aspects, such as energy consumption in production (environmental sustainability) and the final price on the market (economic and social sustainability), may not be sufficiently justified for consumers (Fresán et al., 2020; Macdiarmid, 2022; Szenderák et al., 2022). Despite all efforts to make these PB alternatives similar to conventional products, there are still many sensory issues. Bitterness is just one concern; other sensory issues, like texture and off-flavours, also hinder the acceptance of these products (Moss et al., 2023; Tireki et al., 2024). For example, from 109 cheese alternatives tested, none of these could mimic the meltability of dairy cheese (Nicolás Saraco & Blaxland, 2020) and 4 AB burgers were overall juicier than 4 PB burgers cooked in the same conditions (Zhang et al., 2024).

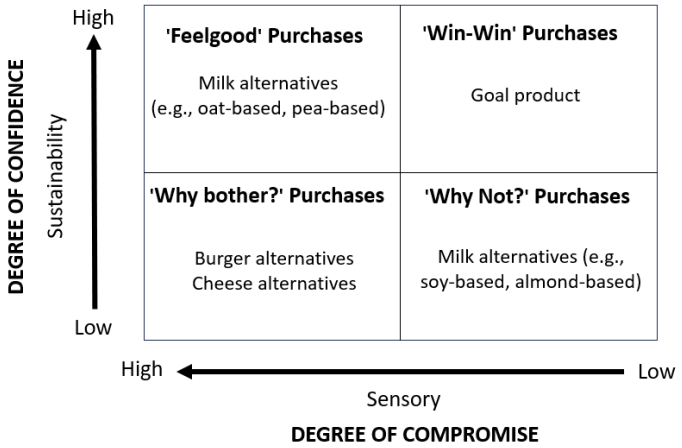

Figure 4. Plant-Based Alternative Consumer Perception Matrix. Based on the author's interpretation of the Green Purchase Perception Matrix by Peattie (2001).

Another example is PB beverages that are made from various raw materials. For instance, soy- and almond-based beverages can be seen as 'Why Not?' products (Figure 4). These products have one of the largest shares in the PB beverage market (Grand View Research, 2023), as these products also have less often issues with bitterness (Part et al., 2023; Vaikma, 2023). Although the production of both beverages has a lower impact on global warming compared to cow milk (Geburt et al., 2022), their raw material cultivation is associated with other environmental issues, such as deforestation and freshwater ecotoxicity for soy (Geburt et al., 2022; Poore & Nemecek, 2018), and bee mortality and water scarcity for almonds (Geburt et al., 2022; Wade et al., 2019). Among PB beverages, almond and soy beverages have some of the highest climate impacts, at 0.8 and 0.7 kg of CO_2 per kg of almond and soy beverages, respectively, compared to the oat beverage, which has the lowest impact at 0.3 kg CO_2 per kg product (Potter et al., 2020). However, this can largely depend on the specific market – previous values are based on the relevance of Sweden, but it has also been shown that organic soy beverages acquired from soy beans in Switzerland can have a similarly low environmental impact as oat beverages (Geburt et al., 2022). Nonetheless, soy and almonds are one of the most common plant-derived food allergens (Worm et al., 2021 as cited in Präger et al., 2023; Vojdani et al., 2018), reducing their health sustainability for many consumers.

On the contrary, oat- and pea-based beverages can be seen as 'Feelgood' products. These raw materials have environmental potential as they grow easily in various regions (Marshall et al., 2013; Mecha et al., 2023) and health intolerances are not as common (Feng et al., 2022; Gilissen et al., 2016; Taylor et al., 2021). Furthermore, they have great nutritional benefit from dietary fibre, protein and good amino acid content (Alemayehu et al., 2023; Marshall et al., 2013; Mecha et al., 2023; Shanthakumar et al., 2022; Taylor et al., 2021). The problem with these products, however, is often their greater bitterness due to the specific molecular composition, e.g. bitter fatty acids and saponins can be found in oats as well as peas (Günther-Jordanland et al., 2020; Ongkowijoyo et al., 2023).

These are just a few examples of different PB products. The global market, of course, offers a much broader range. However, it has been addressed that the commercial availability of PB proteins is somewhat limited, and the existing supplies need greater diversification (Hoehnel et al., 2022).

1.2.1 Degree of compromise for purchasing plant-based alternatives through the issue of bitterness

The current study looks at the degree of confidence from the bitterness perspective. Even though bitterness can sometimes be a desirable attribute (e.g. coffee, chocolate) (Nolden & Feeney, 2020), it has been shown that bitterness reduces consumers' acceptability of PB foods (Drewnowski & Gomez-Carneros, 2000; Pagliarini et al., 2021), including PB alternatives for milk and meat (Ettinger et al., 2022; Moss et al., 2022; Pramudya et al., 2019). Furthermore, consumers who are more sensitive to bitterness tend to consume fewer vegetables and more sweet foods (Sandell et al., 2014). The negative association is understandable as bitterness has evolved as a defence mechanism to avoid toxic compounds (Breslin, 2013; Jalševac et al., 2022; Spaggiari et al., 2020). Many other factors make bitterness topic even more complicated.

First, the **molecular level.** Taste receptors are cells located within taste buds that can bind to and interact with specific taste molecules (tastants), facilitating the detection of taste and transmitting the information to the brain through neurons (McLaughlin & Margolskee, 1994). However, the receptor mechanisms vary based on the tastant. Sourness and saltiness can be perceived by ion channels, which means that tastants enter

the taste cell and release positively charged sodium ions (Na+) or hydrogen ions (H+) (Breslin & Spector, 2008; McLaughlin & Margolskee, 1994; Nolden & Feeney, 2020). Other taste modalities are detected by G protein-coupled taste receptors (GCPRs) such as TAS1R for sweet and umami, and TAS2R for bitterness (Breslin & Spector, 2008; Jalševac et al., 2022; Nolden & Feeney, 2020). GCPRs are more complex mechanisms that can be viewed as processing units (Breslin & Spector, 2008). GCPR receptor has seven transmembrane domains and when a taste molecule binds to the receptor, it undergoes a conformational change (Bachmanov & Beauchamp, 2007; Jalševac et al., 2022). This induces interaction with the G protein (i.e. GTP-binding protein), which consists of three subunits – alpha, beta, and gamma (Jalševac et al., 2022; McLaughlin & Margolskee, 1994). As a result, internal chemical signals are activated that transmit secondary messengers (e.g. calcium ions, cyclic nucleotides) with each reaction product activating the next reaction (Ahmad & Dalziel, 2020; McLaughlin & Margolskee, 1994). This signalling cascade can elicit diverse cellular responses; for instance, in the case of bitterness, an elevated level of Ca^{2+} in the cell can trigger the release of the neurotransmitter ATP that forwards the signal to the nerves (Jalševac et al., 2022).

Individuals have approximately 25 bitterness receptors, whereas less than 10 for sweet and umami (Diepeveen et al., 2022; Spaggiari et al., 2020). The exact mechanisms by which salts and acids are transduced in the taste buds are not yet fully understood (Diepeveen et al., 2022; Munger, 2016), as they involve signal transmission through ion channels instead of receptor proteins. Thus, as far as known, bitterness can be induced by the most diverse set of compounds compared to other tastants. In PB alternatives, phenols, saponins, and peptides are one of the most common bitter compounds in PB foods (Leonard et al., 2023; Y. Wang et al., 2022), though not exclusively. It is also known that the proportion of bitter compounds varies by specific plant, e.g. Fenwick & Oakenful (1983) showed varying saponin content of 20 common food plants. Furthermore, the proportion of bitter compounds can differ by the plant variety, the growing conditions, the harvest practices and the treatment processes (Heng et al., 2006; Leonard et al., 2023).

Secondly, the **physiological level.** The tongue is covered with four types of papillae: filiform, fungiform, circumvallate and foliate papillae (McLaughlin & Margolskee, 1994; Nelson, 1998). However, the number of taste buds on papillae varies, although filiforms contain none (Nelson, 1998). Others contain taste buds, but the circumvallate papillae usually have almost half the number of taste buds (Witt & Reutter, 2015). There are approximately 4,600 taste buds per individual (Witt & Reutter, 2015), and each taste bud contains 50–100 taste receptors (Breslin & Spector, 2008; Nelson, 1998). The individual differences in taste perception are affected by varying amounts of taste buds (Witt & Reutter, 2015) and allelic variation in receptor genes (Bachmanov & Beauchamp, 2007). For example, various bitter receptors (TAS2Rs) may contain polymorphisms in genes, and thus the same receptor may vary in genes between individuals (Hayes et al., 2013). A previous study demonstrated that polymorphisms in TAS2R genes can lead to varying receptor activities and taste sensitivities to three various bitter molecules (Pronin et al., 2007). Thus, there may be distinct consumer groups with genetic variations, highlighting the need to understand preferences for input into food development (Nolden & Feeney, 2020).

A person may also experience changes in their perceptions over time. On one hand, taste cells in the taste buds are rapidly replaced, with a lifespan from 10 to 14 days (McLaughlin & Margolskee, 1994). This allows one to recover from taste loss (Otsubo et al., 2022) or improve taste sensitivity over training and experience (Höhl &

Busch-Stockfisch, 2015), as it is not a permanent system. On the other hand, while foliate papillae are constant in life, vallate and fungiform are more numerous in younger people (Witt & Reutter, 2015). Thus, the sensitivity level to bitterness in PB foods is also likely lower for older (46–60 y. o.) compared to younger respondents (Pagliarini et al., 2021).

Third, the **level of exposure**. Some studies have shown that gender and ethnicity, due to different genotypes/phenotypes, influence taste perception (Williams et al., 2016; Yang et al., 2020). However, the evidence on demographic effects is not conclusive. Pagliarini et al. (2021) showed in their paper that bitter sensitivity to PB foods did not show significant differences by gender. Another study by Mennella et al. (2005) commented on ethnic differences in taste perception, suggesting that cultural background is involved in these demographic differences.

It is well-established that the environment plays an important role in taste perception (Birch, 1999; Wardle & Cooke, 2008). Moreover, environmental factors can override even the genetic influences (Hayes et al., 2013; Mennella et al., 2005; Navarro-Allende et al., 2008). For instance, environmental factors may be related to long-term habits. Research suggests that certain food consumption behaviours are linked to sensitivities to all taste modalities, such as the consumption of pungent foods, coffee, and ketchup (Puputti, Hoppu, et al., 2019). Bitterness perception has been shown to be influenced by preferences and consumption of other bitter foods such as certain vegetables (Cavallo et al., 2019; Cliceri et al., 2018; Pagliarini et al., 2021) or coffee (Lipchock et al., 2017). Other non-food-related factors, including smoking (Jacob et al., 2014), stress (Noel & Dando, 2015), physical exercise (Gauthier et al., 2020) and menstrual cycle (Barbosa et al., 2015), can further affect taste perception. Moreover, momentary influences such as current mood (Noel & Dando, 2015), food pairings and surrounding music (Cavallo et al., 2019) can alter how food taste is perceived. Thus, the perception of taste (including bitterness) depends not only on differences between people, but also on the specific situation.

In conclusion, taste perception overall is multifaceted and highly complex. Some consumers are significantly more sensitive to all tastes compared to the average consumer (i.e. hypersensitive tasters), while others are notably less sensitive (i.e. hyposensitive tasters) (Puputti, Aisala, et al., 2019; Puputti et al., 2018). Consequently, it is unlikely to meet all consumer expectations for PB alternatives simultaneously (Giacalone et al., 2022). Nevertheless, there are strategies available to mitigate bitterness-related challenges. Mittermeier-Kleßinger et al. (2021) describe that, with increasing knowledge about the occurrence of off-flavours (including bitterness), new strategies are being developed to eliminate or minimise the undesired compounds. This starts with crop improvement through growing conditions as well as selective breeding. The resulting PB raw material can be pre-treated to reduce off-flavour compounds, e.g. proper heat treatment and soaking can reduce bitterness (Y. Wang et al., 2022). When producing PB protein powders (used as an ingredient for many PB alternatives), additional processing methods can be used to influence the result. For example, hydrolysing or solvent extraction of proteins to remove unwanted flavour (Mittermeier-Kleßinger et al., 2021; Y. Wang et al., 2022). Many technical nuances in the preparation of the final food product can affect the sensory profile further. Y. Wang et al. (2022) discuss that extrusion (a widely used method for PB meat alternatives) parameters strongly influence the sensory profile. For example, the temperature of extrusion affects lipid oxidation and can lead to off-flavours, including bitterness. Fermentation or using additional compounds (e.g. sugars for the Maillard reaction) can be used to adjust the formation of flavour

compounds (Mittermeier-Kleßinger et al., 2021; Y. Wang et al., 2022). As fermentation is a common technique for dairy products, it is also used to improve the flavour profile of PB dairy alternatives (Harper et al., 2022; Tangyu et al., 2019). Additionally, it is possible to use flavour additives, e.g., seasonings, yeast extracts, bitterness maskers or inhibitors, and/or to modify textural properties to influence flavour release (Mittermeier-Kleßinger et al., 2021; Y. Wang et al., 2022). There are even post-treatment methods to tailor the sensory profile, such as marinating (Mittermeier-Kleßinger et al., 2021). Moreover, packaging and storage conditions have also been studied to understand the development of off-flavours (Leonard et al., 2023).

1.2.2 Degree of confidence for purchasing plant-based alternatives through the sustainability dimensions

The current study looks at the degree of confidence from the sustainability perspective. In research, sustainability is most often studied as a three-dimensional structure consisting of environmental, economic and social pillars, e.g. in entrepreneurship (Dhahri & Omri, 2018; Hanaysha et al., 2022; Tur-Porcar et al., 2018), in marketing (Bolton, 2022; Lim, 2022), and in food field (Aiking & de Boer, 2020; Bellassen et al., 2022; Maynard et al., 2020). Purvis et al. (2019) explains that the origins of this three-dimensional sustainability model can be traced back to the Brundtland (1987) report and later articulated in Agenda 21 (United Nations, 1992). This model continues to be widely used today, as seen in the 2030 Agenda for Sustainable Development (United Nations General Assembly, 2015) with its 17 Sustainable Development Goals. However, Purvis et al. (2019) also argue that its universal application has been unjustifiably assumed and lacks sufficient theoretical grounding.

In response to this, alternative approaches to sustainability have been explored depending on the research objectives. For example, Millward-Hopkins et al. (2018) included an additional technical domain as a fourth dimension in the context of resource recovery from waste. Pickering et al. (2022) excluded the environmental dimension and added institutional, epistemic, and technological dimensions in the context of democratic practices in environmental governance. Additionally, some researchers have proposed entirely new models of sustainability. Seghezzo (2009) proposed a five-dimensional sustainability that includes time (permanence), human (persons) and three dimensions of space (cultural, geographical and physical place) for use by academics and policymakers in sustainable development. These examples highlight the ongoing evolution of sustainability frameworks.

In line with these examples, this thesis argues that the classical three-dimensional model of sustainability is insufficient as it overlooks the human aspect. Purvis et al. (2019) highlight that in the traditional three-dimensional approach, the human aspect is implicitly embedded within other dimensions, such as ensuring well-being through environmental factors (e.g., safe water, waste recycling) and social factors (e.g., healthcare provision, food security), as well as economic factors (e.g., financial protection for healthcare). To address this limitation, some sustainability models have expanded the three-dimensional approach by introducing a fourth dimension. An earlier example is Goodland's (2002), which distinguishes the fourth dimension as 'human' sustainability. This includes maintaining human capital, such as through health, education, and skill development. Another approach to more human aspect through the fourth dimension, is through culture. Nurse (2006) proposed culture as the fourth dimension (and central!) pillar, encompassing cultural heritage, traditional knowledge, cultural entrepreneurship, while Astara (2014) and Najjar (2022) introduced culture

and cultural-historical dimensions (respectively). These adaptations acknowledge the importance of the human aspect in sustainability and suggest that the classical three-dimensional model may be too broad for certain contexts, such as in the study of PB alternatives.

As discussed in Chapter 1.1.2, the growing interest in sustainability issues has contributed to the rising popularity of PB alternatives, such as PB beverages. FAO/WHO (2019) defines sustainable diets as 'dietary patterns that promote all dimensions of individuals' health and wellbeing; have low environmental pressure and impact; are accessible, affordable, safe and equitable; and are culturally acceptable'. This definition reveals five key topics: health (as 'health and well-being'), environment (as 'having low environmental pressure and impact'), economic (as 'accessible, affordable'), social (as 'safe, and equitable'), and culture (as 'culturally acceptable'). In this thesis, the environmental, economic, and social dimensions follow the classical approach. However, health is treated as an independent dimension because consumers often make sustainable product purchasing decisions based on perceived health benefits. For example, consumers might prioritise health in purchasing organic food (Rana & Paul, 2020), 'green' cosmetics (Testa et al., 2024), 'green' furniture (Xu et al., 2020), remanufactured electronics (Aydin & Mansour, 2023), as well as PB alternatives (Pointke, Ohlau, et al., 2022). Further, it has been criticised that health is primarily addressed through Goal 3 ('Good health and well-being') in the Sustainable Development Goals, limiting its integration with other sustainability objectives (Waage et al., 2015) and overlooking opportunities to measure health aspect both objectively and subjectively (Eckermann, 2018).

In contrast, while culture is recognized as one of the key topics in sustainable diets based on FAO/WHO (2019) definition, it is not included in this framework for several reasons. First, culture reflects the subjective norms outlined in the TPB. Although subjective norms are acknowledged in this study as another factor that can influence PB consumption, the primary focus is on (affective and cognitive) attitudes rather than subjective norms. Second, although subjective norms can affect sustainable purchasing decisions (Pristl et al., 2021), culture is more diffuse and varies across communities and contexts, making it difficult to isolate as a separate, measurable dimension. In comparison, health has a more direct, personal impact on the attitudes making it more straightforward to assess.

The given thesis takes a four-dimensional approach to sustainability, as demonstrated in Figure 5. Building on the above, this study offers a reformulation of the term 'sustainability' within the context of PB alternatives. Sustainability in this context focuses on creating PB products that satisfy current dietary and nutritional needs (health), while minimising environmental harm, such as conserving biodiversity and reducing greenhouse gas emissions. It also prioritises social fairness, including promoting food security and implementing ethical standards, as well as addressing economic factors like affordability and fostering new economic opportunities within the supply chain. Additionally, to empower consumers to make informed choices that support these various sustainability goals, it is crucial to consider factors like sensory acceptability, product accessibility, cultural values, and transparency in product information.

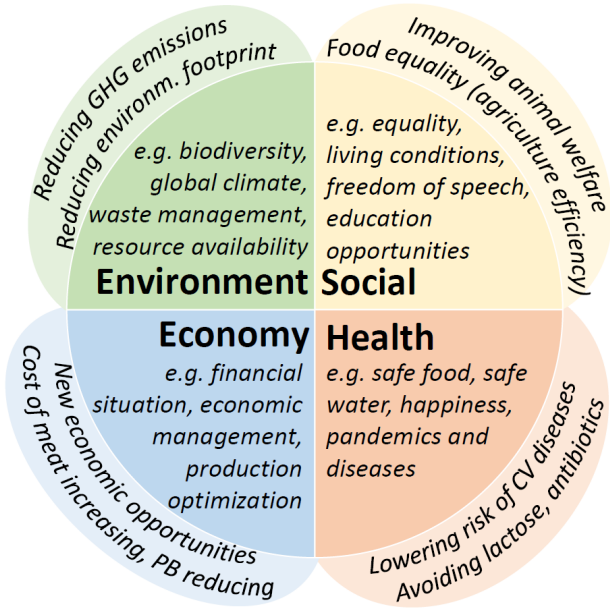

Figure 5. Four-dimensional model of sustainability. The inner circle conceptualises sustainability aspects in general, outer circle brings examples from the PB alternatives context. Compiled by the author based on current Chapter 1.2.2 and Article III. Abbreviations: CV – cardiovascular diseases, GHG – greenhouse gas.

Abovementioned conceptualisation of sustainability in the context of PB alternatives is further elaborated in relation to PB products below. However, it is important to emphasise that perceptions of these conceptualisations can vary depending on the context, such as demographic factors and food category (Sánchez-Bravo et al., 2020).

1. **Environmental reasons.** Global environmental changes and depletion of natural resources has been a serious topic for many years. The current food system is one of the main factors in this issue. Over the years, many scientific studies have highlighted the environmental issues related to animal agriculture, such as greenhouse gas emissions, water and air pollution, changes in freshwater and land use, and biodiversity loss (Abdalla & Lawton, 2006; Errickson et al., 2021; Sakadevan & Nguyen, 2017; Springmann et al., 2018). A review paper by Aleksandrowicz et al. (2016) demonstrated that reducing AB food consumption can lead to a smaller environmental footprint by reducing greenhouse gas emissions, and water and land use. Thus, changing dietary patterns is encouraged since increasing the proportion of PB food will improve environmental sustainability (Godfray et al., 2010). According to a report from FAO/WHO (2019), 'population growth of 2 billion people by 2050 will increase diet-related environmental pressure'. Europe's Bioeconomy Strategy also encourages sustainable food production and consumption (European Commission, 2018).
2. **Social reasons**. On one hand, PB consumption can be related to ethical concerns about food equality. Some foods of animal origin (such as milk) may be difficult to obtain in some regions (Paul et al., 2019). Furthermore, continuing population growth increases the food demand which consecutively creates the need to improve the capability of current food systems (Godfray et al., 2010) and to

alleviate food security issues (Szenderák et al., 2022). The efficiency of agriculture can be increased by reducing the proportion of crops produced for animal feed and other non-food uses, which in turn could increase food availability (Foley et al., 2011)**.** On the other hand, consumers also often turn to PB foods because of moral reasoning. For example, drinking a PB beverage can lead individuals to a sense of ease by reducing their concern about contributing to animal mistreatment (McCarthy et al., 2017).

3. **Economic reasons.** Meat and milk prices have been currently on the rise due to growing demand and higher energy and feed costs, although it is anticipated that it will decrease in the future due to the stabilisation of supply chains (European Commission, 2021; OECD/FAO, 2022). Many consumers are already eating less meat because they feel that meat is too expensive (Kemper et al., 2023). Although PB alternatives can also be rather expensive, consumers may be willing to pay a higher price for PB proteins, possibly if they believe that the higher-priced products are healthier (Tso et al., 2021) or of better quality (H. Wang et al., 2019). While many PB alternative products often require complex processing methods, they still have a lot of potential. If the PB products are made directly from plant ingredients (rather than undergoing more energy-intensive processing), they can have lower processing costs compared to the AB product, such as meat (S. Zhao et al., 2023). Further, for food producers, the PB alternative market may create new economic opportunities in supply chains as well as job creation (Newton & Blaustein-Rejto, 2021).
4. **Health reasons.** Avoidance of dairy products for health concerns is frequently based on lactose intolerance, allergies or doubts about cholesterol levels, and hormone/antibiotic residues (Mäkinen et al., 2016; Paul et al., 2019), as well as skin conditions and digestive issues (Mekanna et al., 2024). There are suggestions that PB diet can also have a positive impact on health, for instance increasing dietary fibre intake and lowering saturated fat intake, and LDL-cholesterol consumption (Bryant, 2022). Further, lowering the risk of cardiovascular diseases (Kim Hyunju et al., 2019; Salter, 2017). Many organizations promote PB food to reduce the risk of noncommunicable diseases (EUPHA, 2017; WHO, 2021). This rationale may increase consumer confidence in PB alternatives.

However, consuming PB alternatives does not always translate as sustainable behaviour. Further, a PB diet can often have a halo effect on sustainability (Macdiarmid, 2022). These sustainability shortcomings can lower the degree of confidence in terms of the purchase perception matrix. For example:

1. **Environmental uncertainties.** Some raw materials that are often used as the main ingredient in PB alternatives have been previously linked to environmental issues. For example, rice production with mineral nitrogen leaching and soy farming with deforestation (Poore & Nemecek, 2018). Large-scale monoculture production is also a problematic issue in terms of biodiversity and often requires the increased use of fertilizers and pesticides (Macdiarmid, 2022). Overuse of these compounds can have a negative environmental impact on water systems as well as soil (Kerr, 2012). In addition, many PB alternative products are highly processed, especially convenience products, which require more energy to produce and contain various additives (e.g. palm oil, corn syrup), further increasing the environmental impact (Macdiarmid, 2022).

2. **Social uncertainties.** Social pressure can arise from the increasing production of PB materials. For example, the Green Revolution's focus on increasing yields to reduce hunger and poverty increased other social inequalities, such as women's labour in third-world countries (Kerr, 2012). Thus, producers need to pay careful attention to social sustainability such as working conditions and labour practices (Wognum et al., 2011). The transition in agriculture can also be difficult, as external support is always needed to introduce new sustainable technologies and farming practices (Bernard et al., 2014). This means not only financial support but also providing job security. Furthermore, the availability and affordability of PB alternatives remain a challenge at present (Fresán et al., 2020; Reipurth et al., 2019), which may still call into question the issue of food equality in certain markets.
3. **Economic uncertainties.** Consumption of PB alternatives is typically not related to the economical aspect due to the higher price of PB products compared to conventional products (Beacom et al., 2022; Macdiarmid, 2022; ProVeg International, 2020; Schiano et al., 2020; Szenderák et al., 2022; Tso et al., 2021). This is mostly due to their high production cost because of the various methods and raw materials used to produce PB alternatives (S. Zhao et al., 2023). Achieving a competitive price is one of the most critical aspects of convincing consumers to purchase plant-based alternatives and transition to sustainable food (Mekanna et al., 2024; Szenderák et al., 2022).
4. **Health uncertainties.** There has been criticism that PB alternatives have poor nutritional quality (Mäkinen et al., 2016; Tangyu et al., 2019), are often ultra-processed (Hu et al., 2019; Macdiarmid, 2022; McClements, 2023; Wickramasinghe et al., 2021) and some materials, also, allergenic (Reyes-Jurado et al., 2021; Silva et al., 2020) or antinutrient (Nath et al., 2022; Paul et al., 2019). Increased consumption of PB products can potentially lead to higher exposure to pesticides and heavy metals (FAO & WHO, 2019). Even research lacks consensus, with one side claiming that PB foods that are highly processed have high energy density and high sugar/fat content (Macdiarmid, 2022), while the other side argues that these characteristics do not describe PB alternatives at all (Bryant, 2022). Further, while research shows that PB alternatives offer a healthy change in diet, consumers often feel the opposite as they seek aspects such as perceived naturalness (Bryant, 2022).

One way to communicate these various sustainability aspects is using labelling. This can help to build consumer confidence in sustainable purchases but requires a well-established and regulated system (D'Souza et al., 2021; Seifi et al., 2012; Setyawan et al., 2018; Wognum et al., 2011). Many authors have criticised the current situation because sustainability communication (such as labels) is often not sufficiently transparent (Calderon-Monge et al., 2020; Mekanna et al., 2024; Stöckigt et al., 2018; van Bussel et al., 2022). As consumers are more conscious of sustainability, they necessitate clear sustainability cues in food innovation (Perez-Cueto, 2020). For example, consumers born between the mid-1990s and early 2010s in Finland emphasised their expectations for more fact-based information about carbon footprint, global benefits and dietary shifts to improve their engagement in sustainability (Kymäläinen et al., 2021). If suppliers offer clear sustainability information, consumers are more inclined to support sustainable development (Stöckigt et al., 2018). This means that it is possible to enhance consumers' confidence regarding the sustainability of products.

2 Research methodology

2.1 Overall research design

The methodological decisions stem from the pragmatism approach. Pragmatist philosophy does not look for absolute truth but looks at truth as something that is constantly evolving since beliefs and understanding can shift with new insights gained over time (Krägeloh, 2006). For example, scepticism toward PB alternatives may diminish over time as consumers become more informed about the sustainability impact (assuming the product has a high level of sustainability, as PB alternatives can vary in this regard), especially given that sustainability is already a key motivator for many consumers today (Fehér et al., 2020; Graça et al., 2019; Haas et al., 2019; Pointke, Ohlau, et al., 2022). Thus, the research is practice-oriented as it is directed towards anticipated consequences (i.e. increased consumption of PB alternatives) rather than antecedent phenomena (Cherryholmes, 1992; Rahi, 2017). Consequently, the perception of PB alternatives evolves, leading to a shift in what is considered the 'truth'.

It has been argued that dominating positivist and interpretivist approaches in consumer research does not allow as much flexibility in a dynamic real-life environment as pragmatism, which often leads to a gap between academics and practitioners (Majeed, 2019). Further, pragmatism is a pluralistic approach (Rahi, 2017) as people themselves can have multifaceted opinions on certain topics (Majeed, 2019). The current thesis recognises the diverse perceptions of sustainability as well as sensorics by exploring these varying perspectives. While PB alternatives are often promoted due to their sustainability potential, real-life behaviour can be contradictory based on the consumers' perception. Varying perception of the sensory profile makes this issue even more complex.

The current thesis is quantitative, although pragmatism is often combined with mixed methods research (Denscombe, 2008; Morgan, 2014). This association lies in history where the interest in pragmatism increased with the emergence of mixed methods research (Morgan, 2014). However, pragmatism does not exclusively practice any particular technique (Denscombe, 2008; Rahi, 2017). Pragmatism is not in itself a sufficient justification for the use of mixed methods, even though it is sometimes regarded as a 'fusion of approaches' (Denscombe, 2008). Pragmatism offers a versatile philosophical research framework that allows researchers to choose both quantitative and qualitative approaches based on what best suits the topic (Morgan, 2014; Rahi, 2017).

As this multidisciplinary thesis combines natural sciences (sensory research on the food technology field) and social sciences (consumer research on the marketing field), this study is by its nature a mixture of different quantitative methods – starting from instrumental analysis at the compound level to consumer studies focusing on perception. The author's preference for quantitative data, rooted in her background in natural science, provides a direct pathway to identify a common point of interaction among these disciplines. Furthermore, pragmatism is often accompanied by abductive reasoning, which aims to investigate a particular phenomenon and can suggest new hypotheses by discovering new themes and patterns (Mitchell, 2018). Integrating two disciplines in a study can complement one another, allowing for a more comprehensive exploration of a phenomenon, particularly from the consumer perspective.

Broadly speaking, this study is divided into two themes. The food technology field focuses on the food-internal aspect, i.e. sensory theme (RQ1, RQ2), providing insight into

one of the most important affective factors in the consumption of food. The consumer research part focuses mainly on the food-external aspect, i.e. sustainability theme (RQ3, RQ4), exploring an important cognitive factor for PB alternative consumers. Looking at PB alternatives from these two perspectives can provide insight into the prevalent factors influencing the consumption (behaviour) of PB beverages (the largest category within PB alternatives), which is the aim of the study.

2.2 Methods for data collection and analysis

All RQs are empirically investigated using various quantitative methods, which can generally be categorised as follows: I. Instrumental analysis, II. Sensory profile analysis, and III. Consumer studies. For a comprehensive overview, please refer to Table 1 on the next page.

I. Instrumental analysis served as an introductory method for this research on PB beverages. Before exploring consumer perception, it is necessary to understand the characteristics of these products. As part of **RQ1**, the goal was to identify the key volatile compounds that may influence the final sensory profile. While this study emphasizes the importance of taste in consumer food behaviour, and volatile compounds are typically associated with aroma, it is important to note that odour and taste strongly interact (Y. P. Chen et al., 2023; Noble, 1996), as also shown with PB dairy alternatives (Greis et al., 2022). Furthermore, odour often predicts certain taste nuances (Faridi Esfanjnai & Mohebbi, 2023; Stevenson et al., 1999) and can enhance or reveal other flavour characteristics (Small & Prescott, 2005). As mentioned earlier, this is due to volatile compounds being released in the retronasal cavity (Pu et al., 2022). Therefore, comparing quantitative data with odour and taste sensory values provides valuable insights into the key compounds influencing the flavour profile of PB beverages.

For this purpose, 90 PB beverages available on the Estonian market were measured using Gas Chromatography/Mass Spectrometry/Olfactometry (GC/MS/O). Volatile compounds were extracted using solid-phase microextraction, in which a fibre (SPME StableFlex™; Sigma-Aldrich, Saint Louis MO, USA) collected the volatile compounds from the headspace at 60 °C for 40 minutes. The extracted compounds were quantified and identified using the Micromass GCT Premier gas chromatography system (Waters, Milford MA, USA). To identify the key volatile compounds in the aroma profile, gas chromatography-olfactometry was conducted by coupling gas chromatography instrument Agilent 7890A (Agilent Technologies Inc., Santa Clara CA, USA) with an ODP sniffing port (Gerstel Inc., Linthicum MD, USA). Two trained assessors evaluated the samples in two replicates, where they were asked to describe the odour as well as the intensity (5-point scale). The average content of volatile compounds was investigated to determine which compounds were the most evident (GC/MS) and which compounds were detectable in the aroma profile (GC/O) in various samples.

II. Sensory profile analyses were conducted in both food-internal studies. All the sensory analyses were conducted in TFTAK (Tallinn, Estonia) in a dedicated sensory room with minimised external influences (in accordance with ISO 8589:2007). Sensory analyses were conducted by TFTAK's internal sensory panel consisting of highly trained assessors with previous experience in sensory analyses. All evaluations were conducted as blind tests, with samples coded using random three-digit numbers and presented in varied orders to mitigate potential bias and carryover effects (Macfie et al., 1989).

Table 1. Overview of the research design of the thesis. Compiled by the author.

Structural element	Publi-cation	Rele-vance	Research aim	Participants*	Method (data collection)	Method (data analysis)
Food-internal	Article I	RQ1	To get a sensory overview of the PB beverage market in Estonia (90 unflavoured products available during Jan 2020)	1) 2 trained assessors (aroma analysis) 2) 10 trained assessors (sensory analysis)	Quantitative: GC/MS/O (aroma analysis), RATA (sensory analysis)	Descriptive statistics; PCA; PLSR; PLS-DA
	Article II	RQ2	To investigate individual differences in bitterness perception of various PB bitter compounds	1) 12 trained assessors (sensory analysis); 2) 100 untrained participants (consumer study). Collected between Oct 2021 and Apr 2022	Quantitative: PROP-test (sensory analysis), descriptive analysis (sensory analysis and consumer study)	Descriptive statistics; ANOVA; PCA; Wilcoxon rank-sum test; Chi Squared test; Spearman's correlation (ρ)
Food-external	Article III	RQ3	To explore various dimensions of sustainability in different consumer segments	1) 1019 consumers (50% EE, FR, IT, SE) between Apr and Jun 2022; 2) 926 consumers (52% IT, 48% SE) in Oct 2022	Quantitative: SDPS (consumer study)	EFA; CFA; Construct validity; Convergent validity; Cross-validity; Invariance tests; Descriptive statistics; Kruskal-Wallis test; Mann-Whitney U test; k-means clustering; PCA
	Article IV	RQ3, RQ4	To determine how sustainability is perceived in the context of PB beverage alternatives	600 consumers (50% IT and SE) in Oct 2022	Quantitative: SDPS (consumer study), Conjoint analysis (consumer study)	HB Mixed Logit Model; Latent Class Segmentation; Wilcoxon rank-sum test; Chi Squared test; Spearman's correlation (ρ)

** Participants not referred to as 'sample' to allow comparability, since in sensory studies, the tested product serves as the sample, while participants are regarded as part of the method. In consumer studies, however, it is the opposite, where participants are considered the sample.*

Getting a sensory overview of Estonian beverages for **RQ1** continued using a Rate-All-That-Apply (RATA) method with a trained sensory panel consisting of 10 assessors (average age of 31 years). In RATA, participants are asked to select the relevant terms from a given list and to rate their intensity (Ares et al., 2014) for a given sample. This method is well-implemented in food research, showcasing rapidity and discriminative ability (D. Kim et al., 2023; Nishida et al., 2021; Vidal et al., 2018). The frequency and average scores (scale 1–5) of selected terms were investigated based on descriptive statistics. Given the variation in the use of specific terms among different samples and assessors, standardisation was implemented to enable comparability through the application of Dravnieks' scores (Vidal et al., 2018). Further, the sensory profile of samples based on their raw material (main ingredient) was investigated using Partial Least Squares Discriminant Analysis (PLS-DA) and Principal Component Analysis (PCA). Volatile compound data (GC/MS/O) was also integrated with RATA using Partial Least Squares Regression (PLSR) to identify compounds most likely associated with particular sensory terms based on the raw material.

Shifting from a general sensory profile to the more specific topic of bitterness, **RQ2** investigated individual differences in bitterness perception of PB bitter compounds compared to well-established bitter standards. The bitterness level of various compounds was evaluated in two replicates by a panel of 12 assessors (average age of 31 years) using a quantitative descriptive approach. Sensory panel evaluates a specific attribute on a given scale, in this case, bitterness intensity on a 10-point scale ranging from 0 ('none') to 9 ('very strong'). Furthermore, a PROP test was conducted. A method in which the intensity of propylthiouracil (PROP) is assessed on a General Labeled Magnitude Scale and enables the categorisation of individuals as super-tasters, medium-tasters, and non-tasters based on their scale responses (Tepper et al., 2001). Panel performance was assessed through ANOVA analysis, and assessor/stimuli variances were visualised using PCA plots. Overall bitterness perception was analysed based on descriptive statistics. Spearman's correlation coefficients were employed to explore two aspects: firstly, to examine potential relationships between various bitter compound sensitivities, and secondly, to assess the relationship between PROP taster status and various bitter compound sensitivities.

It must be noted that Estonia was in quarantine lockdown during the COVID-19 pandemic from March 2020 to May 2021, with the first case reported in late February 2020. Sensory data for Article I were collected before the pandemic began, ensuring no impact on the results. In contrast, sensory data for Article II were gathered post-lockdown. Although the post-lockdown context may have had some influence, sensory evaluations were conducted with healthy assessors under controlled conditions, minimising any external factors affecting the results.

III. Consumer studies are the most direct way to explore consumer perception. This was implemented in all RQs, expect for RQ1. However, the approach was different for each. Starting from **RQ2**, this was the first glance into consumers' sensory perception of various PB bitter compounds. Knowing that environmental factors, such as consumption habits of vegetables (Cavallo et al., 2019; Cliceri et al., 2018; Pagliarini et al., 2021), may influence bitterness perception, consumers were recruited based on their consumption habits. A consumer panel of 100 participants (57% omnivores, 43% vegans/vegetarians) participated in April 2022, nearly a year after the COVID-19 lockdown ended in Estonia. Therefore, the pandemic had no or minimal impact on the sensory results. Consumers were presented with oat- and pea-based water solutions (serving as a base for a beverage)

and asked to evaluate the perceived bitterness intensity on a 10-point scale ranging from 0 ('none') to 9 ('very strong'). This was also conducted in a dedicated sensory room (ISO 8589:2007) in TFTAK. Similarly, the samples were coded and presented in varying order. The bitterness level of samples was investigated based on descriptive statistics. Further, significant differences between diet patterns were investigated based on the Wilcoxon rank-sum and Pearson Chi Squared test.

There were multiple studies implemented for investigating **RQ3**. In order to develop a measurement tool for consumer perception of sustainability based on the four-dimensional framework demonstrated above (chapter 1.2.2), the first study (Article III) aimed to develop the Sustainability Dimensions Perception Scale (SDPS). These kinds of measurement tools are often tested and validated based on Exploratory Factor Analysis (EFA), Confirmatory Factor Analysis (CFA), construct and convergent validation. However, this needs an adequate sample size. Using GPower software version 3.1.9.7 (Faul et al., 2009), with an α error probability of 0.001 and the power $(1 - \beta)$ of 0.99, the total required sample size was determined to be at least 626. Since there is no universally agreed-upon rule of thumb for sample sizes (Schmitt, 2011), this study aimed to recruit nearly 1000 consumers as in similar questionnaire development studies using factor analysis (Roininen et al., 1999; Steptoe et al., 1995; Thuy Nguyen & Habók, 2022; J. Zhao et al., 2020). Further, to include participants with more varied opinions, they were recruited from different countries based on the sustainability reports (Eurobarometer, 2020, 2021; Saschs et al., 2021) and their representation of Northern, Southern, Western and Eastern Europe. Thus, the final sample was composed of 1019 consumers (roughly 250 from Estonia, France, Italy, and Sweden) who responded to an online survey between April and June 2022. Factor analysis was able to reduce the length of the questionnaire down to 22 statements (5–7 for each dimension).

The second study for **RQ3** (Article III) was using this newly tested and further refined 22-item questionnaire (SDPS) with another sample (Appendix A5). At this time, recruitment was done only in Italy and Sweden based on previous reports indicating a potential contrast in consumer perception towards sustainability (Eurobarometer, 2020, 2021; Saschs et al., 2021). The final sample consisted of 926 consumers (52% Italy, 48% Sweden) responding to an online survey in October 2022. The data was used to not only re-validate the questionnaire as part of the scale development process (including cross-validation and invariance tests) but also investigate the multi-dimensional perception of sustainability of the consumers. In this case, k-means clustering was visualised by PCA and the significant differences between different clusters were calculated with Kruskal-Wallis and Mann-Whitney U tests.

The last study was conducted primarily for **RQ4**, which investigated the perception of sustainability in the context of PB beverages, although it also touched on RQ3 with multi-dimensional sustainability perception. For this purpose, SDPS was combined with a conjoint study, which participants completed one week apart. Conjoint analysis is a research technique that is commonly used in market studies, including food research (Hendriks-Hartensveld et al., 2022; Jantzi & McSweeney, 2019; Jindahra & Phumpradab, 2023; Szymkowiak et al., 2020; Tekień et al., 2018; Velázquez et al., 2021), to understand how consumers value different attributes of a product. The general idea is to allow consumers to decide between competing products, thus mimicking a market experience (Asioli et al., 2016; Orme, 2010). Consumers are presented with products that have varying characteristics and are asked to make a choice. This process can reveal the most important product characteristics for consumers or consumer groups. As a continuation

of the previous study (Article III), the sample adhered to the same conditions, though it comprised slightly different individuals. The objective was to secure a minimum of 300 respondents (Orme, 2010) per country for the conjoint study, resulting in a total of 600 consumers (50% Italy, 50% Sweden). To focus participants only on their perception of sustainability and not on their consumption patterns, participants were not asked what they would purchase – a traditional approach for a choice-based conjoint study. Instead, the participants were asked to choose the most sustainable product from a selection of conceptual products that varied by their raw material, packaging, storage conditions and labels. For example, Velázquez et al. (2021) similarly changed the task to asking to choose a healthier snack product. This approach was tested in both beverage (milk) and food (burger) contexts to allow for comparison across different product groups, as research shows that sustainability perception can vary by food category (Sánchez-Bravo et al., 2020). Finally, the conjoint data was analysed using the HB Mixed Logit Model and Latent Class Segmentation. Differences between resulting clusters were investigated by Wilcoxon Rank Sum and Chi Squared tests. The association between sustainability dimensions and product characteristics were investigated using Spearman's correlation coefficients.

3 Results and discussion

The given section gives an overview of the results and discussions based on RQs 1–4 (subchapters 3.1–3.4 accordingly). The last part (subchapter 3.5) brings together the four studies in a common discussion.

3.1 Sensory versatility of various raw materials in currently available plant-based beverages

The investigation of the sensory properties of existing PB beverages available addressed RQ1, which was investigated in Article I. In this study, a total of 90 unflavoured PB beverages were collected from the Estonian market in January 2020, each consisting of one main PB raw material (not blends of various raw materials). There were products available with 11 different raw material ingredients, which seems like a relatively wide range of products. However, there was limited choice for certain raw materials. Following a categorisation by Sethi et al. (2016), the products were mainly cereal & pseudo-cereal based (42%) and nut-based (41%), but limited choice of legume-based (16%) and seed-based (1%) products. In addition, the legume-based only consisted of a soy beverage and the seed-based only of a hemp beverage. However, even among the larger categories, some raw materials were more common, such as oat among cereal- and pseudocereal-based and almond among nut-based. Compared to the more limited options in the same category, such as quinoa (1%) among cereal- and pseudocereal-based or brazil nut (1%) among nut-based beverages.

It was confirmed in Article I that RATA is applicable for sensory mapping such a large set of products with wide usage of terms and providing enough discrimination between samples. Overall, in at least half of the evaluations terms such as darkness (appearance), greyness (appearance), sweetness (taste, odour), astringency (taste) and wateriness (texture) were selected. These observations point to certain potential shortcomings when produced as a potential milk alternative. This is further suggested by the finding that only 18% of evaluations included a selection of the term ‘dairy-like’. Furthermore, this was more often related to nut-based beverages and less often to cereal-based beverages. This may be related to the finding that cereal-based beverages tended to be waterier in texture, darker in appearance and often had specific odour/taste nuances (e.g. earthy, astringent, bitter) compared to milder nut-based beverages with fuller texture. Although this paper focused more on the sensory perception of specific compounds in taste, it is important to note that taste perception is very much influenced by mouthfeel (Braud & Boucher, 2020). Having a thicker consistency can lead to a fuller body in mouthfeel but also influences the release of taste/flavour compounds during consumption. However, it should be noted that a more recent publication suggests that consumers associate soy-based milk alternatives most closely with dairy-like characteristics (Jaeger, Dupas de Matos, et al., 2024). This discrepancy may arise from differences in the products available in the New Zealand market or the methodologies used. Current study employed a trained sensory panel focused on objective evaluation, whereas Jaeger, Dupas de Matos, et al. (2024) used an untrained consumer panel that may have been influenced by factors such as familiarity and habitual use, as soy is one of the most widely consumed milk alternative (Mäkinen et al., 2016).

The samples were distinguishable in Article I through sensory analysis based on their raw material. Cereal and pseudocereal beverages (e.g., oat, rice, buckwheat, quinoa) were generally described with cereal-like odour and taste nuances, nut-based beverages

(e.g., almond, coconut, hazelnut, cashew, Brazil nut) as nutty, legume-based beverages (soy only) as leguminous, and seed-based beverages (hemp only) as hay-like. However, each type often displayed unique characteristics in addition to the expected ones. These nuances can be linked to the composition of the raw materials. For instance, the nut-based category (Figure 6.A, on the next page) demonstrated that nuttiness is much more diverse in sensory perception than this one term was able to encompass. Coconut nuttiness was linked to various lactones (massoia lactone, decalactone) that according to PubChem database (S. Kim et al., 2019) have sweet and creamy odour characteristics. Almond nuttiness was associated with benzaldehyde, a compound with a characteristic almond-like aroma (S. Kim et al., 2019), present at the highest concentration in the almond data. Hazelnut nuttiness was derived from various pyrazines (2-ethyl-6-methyl pyrazine, 2,3-dimethyl-pyrazine) contributing roasty peanut nuances (S. Kim et al., 2019). Interestingly, some samples resembled a different raw material category in sensory profile. For example, rice beverages, despite belonging to the cereal category, tended to be leguminous. This appeared to be associated with earthy and waxy odour compounds, such as decanal and methyl ester octanoic acid (S. Kim et al., 2019), as illustrated on (Figure 6.B, on the next page).

For producers, a key takeaway is that the sensory profile of the same PB raw material can vary depending on the recipe, from the origin of the raw material to the specific production techniques. For example, Article I discusses that pyrazine (compounds with roasty, nutty aromas) content depends on roasting conditions like time and temperature (Marzocchi et al., 2017). However, heating can also enhance non-characteristic nuances. Decanal, a compound with waxy, fatty aromas (S. Kim et al., 2019) found in rice beverages and associated with inducing leguminous nuances (Figure 6.B), can increase with heat. Similarly, the soapiness perceived in coconut (Figure 6.A) may result from specific ethyl ester compounds (e.g., ethyl ester octanoic acid, ethyl ester decanoic acid, ethyl ester hexanoic acid) that exhibit waxy, oily odour nuances (S. Kim et al., 2019) and can also be enhanced by heat treatment (Suaniti et al., 2019). Dimethyl sulphide, linked to aftertaste nuances like bitterness and astringency, was found in oat (Figure 6.B), hemp and soy samples. It has cabbage, sulphurous, gasoline odours (S. Kim et al., 2019) and its content may also increase with heat (Morisaki et al., 2014). Additionally, soy and hemp samples contained some alcohol and aldehyde compounds (hexanal, hexanol, pentanal) that can be associated with green, earthy, hay-like nuances. These compounds typically result from lipid oxidation (Ghorbani Gorji et al., 2019; Tangyu et al., 2019) which can occur under unsuitable storage conditions, but may also arise from other treatment methods, such as ultrasound pasteurization (Maia et al., 2025). Interestingly, the soy sample was detected to have the highest quantity of vanillin, although these were sold as unflavoured samples. Article I suggests that vanillin could have been used to mask these undesired flavour nuances.

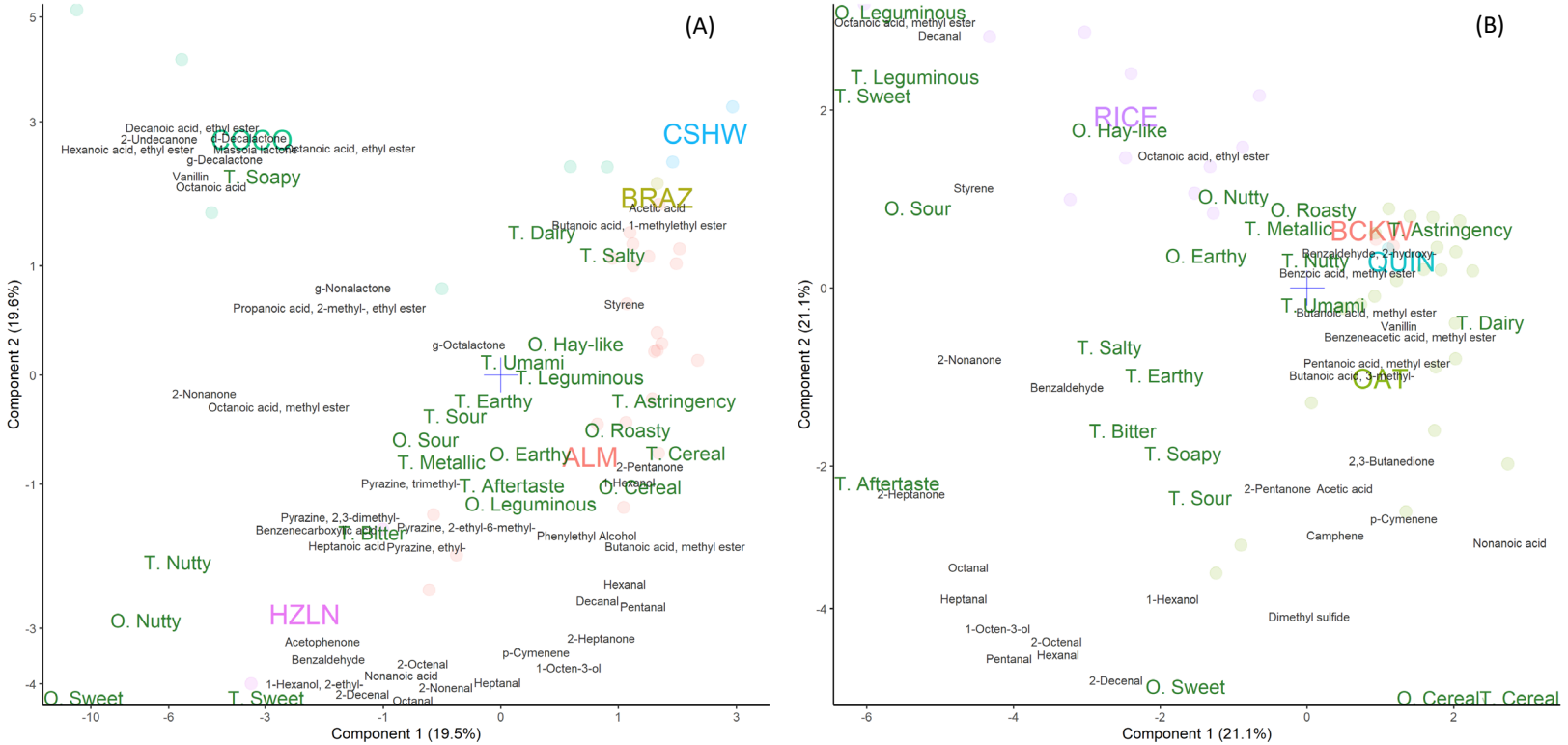

Figure 6. Volatile compounds and sensory characteristics of different nut-based beverages (A) and cereal and pseudocereal beverages (B). PLSR model on mean GC data (compounds identified with GC-MS and GC-O; black text) and mean sensory data (including only odour and taste attributes; green text) on a nonlinear scale. Abbreviations: O for odour and T for taste. Source: (A) from Fig. 5 in Article I and (B) from Fig. 4 in Article I.

Suggesting how affective nuances, such as sensory perception, translate into real-life behaviour is challenging to conclude based solely on this study. This is primarily due to the limited behavioural studies on PB beverages available to the authors' knowledge. Additionally, this study did not investigate consumer perceptions but instead focused on sensory characteristics determined by a trained panel. Consumer studies have shown the key attributes for sensory liking in PB dairy alternatives (e.g. milk, cheese, yoghurt, ice cream alternatives) including creaminess (Greis et al., 2023; Jaeger, Jin, et al., 2024, 2024; Vaikma et al., 2025) and dairy/milky taste (Greis et al., 2023; Jaeger, Dupas de Matos, et al., 2024; Vaikma et al., 2025). Since taste in PB beverages is one of the most important determinants in consumer preference (Su, Gao, et al., 2024), this supports the earlier suggestion that nut-based beverages (perceived by sensory panellists as more dairy-like with a fuller texture) hold the greatest potential in terms of sensory appeal. A study with Spanish consumers by Mustapa et al. (2024), based on the TPB model, found that sensory characteristics of PB dairy alternatives significantly influence purchase intention. Specifically, the more similar or superior a PB product is to its conventional AB counterpart, the higher the purchase intention. These findings highlight the role of affective factors in shaping behaviour, as previously suggested. However, it has also been shown that consumers who frequently consume PB beverages are more likely to appreciate ingredient-specific nuances, such as sweetness, nuttiness, cereal, and coconut flavours (Jaeger, Dupas de Matos, et al., 2024). This indicates that real-life consumer purchase behaviour can be more nuanced regarding sensory preferences. Therefore, sensory aspects must be investigated more thoroughly, considering various consumer groups and specific flavour nuances, which RQ2 addresses in terms of dietary habits and bitterness perception.

3.2 Sensory challenges with the bitterness in the context of plant-based beverages

Demonstrated by the market situation (Article I), it was evident that oat-based beverages have more often bitter and stronger aftertaste compared to other raw materials. Addressing the RQ2, Article II focused on various bitter compounds that can be found in oat- and pea-based beverages. As discussed in chapter 1.2, they have high sustainability potential, but more often issues with taste bitterness (so-called 'Feelgood' products). Further, almost 1/3 of European consumers are keen to have peas and oats as a main ingredient in their PB diet (Smart Protein, 2021). For this study, various compounds from these PB materials and common bitter reference compounds were acquired. Specifically, caffeine, linoleic acid, linolenic acid, L-tryptophan, quinine hydrochloride dihydrate, propylthiouracil (PROP) as well as oat flour and pea flour.

It was evident in Article II that assessors exhibited wide variation in sensitivity to various stimuli, suggesting a link between molecular and physiological differences in the perception of bitterness. This variability was particularly high for fatty acids (linoleic acid and linolenic acid), oat flour and pea flour, whereas the lowest variability was for L-tryptophan. Moreover, the latter also received the highest overall bitterness intensity score. However, the higher variation pea flour was also generally scored with higher bitter intensity, whereas fatty acids and oat flour were generally perceived as less bitter. A consumer study confirmed that oats are generally perceived to have less intense and less variable bitterness across individuals compared to peas. Furthermore, based on the Wilcoxon test, no significant differences were found between average scores for different diet groups. However, when grouping people into three groups based on their given

ratings on bitterness intensity ('low', 'medium', 'high'), Pearson's Chi Squared test found that there were significantly more omnivores who evaluated pea bitterness 'high' compared to vegetarians/vegans, although diet groups did not show significant differences in bitterness groups for oat flour. Thus, it seemed that while oat bitterness is less often perceived independently from the diet group affiliation, then pea bitterness could be more affected by individual diet habits (associated with the level of exposure).

Even though a highly trained panel was used for sensory analysis in Article II, the variability in scores did not appear to be linked to inadequate training. This was evidenced by individual assessors effectively distinguishing between samples and evaluating them consistently across replicate sessions. As Romano et al. (2008) noted, trained panels do not have non-existent, but just smaller differences in scale usage. Also, the variation in scores between sessions depended on the specific stimuli, with pea flour being the most stable and oat flour and fatty acid scores varying more between sessions. Furthermore, the results did not seem to be related to PROP taster status, although this method has long been used to describe individual differences in bitterness perception. The only bitter stimuli that seemed to be linked with PB raw materials were fatty acids. Linolenic acid showed strong significant correlation with oat bitterness, while linoleic acid showed a moderate correlation. This appeared to be consistent with the higher fat content of oat flour. For the pea samples, no correlation was found for any specific compound. Their bitterness could also be related to certain saponins or lipids, which unfortunately were not available in this study. However, it must be noted that there might be variations in bitterness level based on the raw material's genotype and growing conditions (Mecha et al., 2023; Mel et al., 2023).

Considering individual differences in bitterness perception, it demonstrates the major challenges in developing PB alternatives. It is crucial not only to understand how technological decisions can alter the bitterness profile of a product but also to consider the individual level. First, shifting from a general approach in sensory analysis to the selection of specific bitterness standards for sensory evaluations depending on the objective. Especially given that the variability in the sensitivity of pea and oat bitter compounds can be much higher than for known bitterness standards such as PROP, caffeine, and quinine. Second, given that pea bitterness may be a greater concern for consumers (in terms of distribution and average scores) than oat bitterness, then such characteristics require more testing in product development for pea-based beverages. However, since some consumers are also highly sensitive to oat bitterness, targeted product development strategies are essential to address the challenges associated with both raw materials.

As discussed earlier, literature indicates that bitterness reduces the acceptability of PB beverages (Moss et al., 2022; Pramudya et al., 2019). While there were no direct studies found demonstrating how the bitterness of PB alternatives correlates with lower purchase or consumption frequency, it can be presumed. Multiple studies have shown that taste is one of the most important attributes driving PB food choice decisions (Mäkinen et al., 2016; Mekanna et al., 2024; Su, Gao, et al., 2024). Therefore, it is highly probable that the bitterness of PB beverages influences consumer behaviour. However, since pea-based solutions were perceived as more bitter on average in the current study, it is questionable whether they are also consumed less frequently because of this. These pea-based beverages have a smaller market share compared to other categories, such as soy or oat beverages (Food Navigator USA, 2022; GFI Europe, 2022), but there may be other factors at play, such as being less developed compared to soy beverages, which have long history in Asian culture (Mäkinen et al., 2016).

3.3 Multidimensional perception of sustainability in the context of consumers

To investigate consumer perceptions of sustainability from a multidimensional perspective, Article III introduced a novel scale. As discussed in the original Article III, existing measurement tools were insufficient for several reasons: they often focused on behaviour rather than perception (Bom et al., 2019); targeted specific areas or topics, limiting their broader applicability as perceptions vary across contexts (Sánchez-Bravo et al., 2020); concentrated mostly on one or two sustainability dimensions, primarily environmental (Bangsa & Schlegelmilch, 2020; Sesini et al., 2020); or relied on the UN's three-dimensional model, which may overlook themes such as health (Waage et al., 2015). Consequently, this study developed a robust and validated tool to more effectively capture consumer perceptions of sustainability.

The preliminary 61-item scale was initially developed through insights from sustainability literature (referenced in Article III) and consultations with academic and industry experts (acknowledgements in Article III). This survey asked respondents to rate their agreement with various statements on a 1–7 Likert scale. Each dimension consisted of 15–16 statements (61 in total). The items were refined and tested using factor analysis, resulting in a 22-item scale that was subsequently validated (Table 2). The four-dimensional model showed a good fit, indicating that these dimensions are appropriate for measuring separate factors. All model fit and validity test values, along with their corresponding criteria, are presented in Table 2. Convergent validity demonstrated a strong correlation between constructs measuring similar attributes, while discriminant validity indicated a low correlation between constructs measuring different attributes. Further validation confirmed the model's robustness when tested separately in each country (loose cross-validation) and simultaneously across both countries (configural invariance), with model fit supported by the same criteria (RMSEA, CFI, TLI, GFI, AGFI, PCFI). Additional equivalence tests indicated that not all factors were equivalent (full metric invariance test; $\Delta\chi2 = 48.35$, $p < 0.001$), but some constructs were comparable (partial metric invariance; $\Delta\chi2 = 13.48$, $p > 0.050$). Furthermore, significant differences were found in the relationships between the factors (interfactor covariance equivalence; $\Delta\chi2 = 163.76$, $p < 0.001$) and errors (error variance equivalence; $\Delta\chi2 = 431.44$, $p < 0.001$). In conclusion, the findings confirm the reliability and validity of the SDPS, demonstrating its effectiveness in measuring the intended constructs across different cultural settings. The final version of the SDPS, including all four dimensions and their 22 corresponding statements, is provided in Appendix A5.

Table 2. Model fit, validity, and invariance testing results. Compiled by the author based on Study 2 in Article III.

Model fit, cross-validity and invariance	**Indicators**							
	Absolute fit				**Relative fit**		**Parsimonious fit**	
	χ2/df	*p*	RMSEA	GFI	CFI	TLI	PCFI	AGFI
- Total sample	4.23	<0.001	0.06	0.92	0.94	0.93	0.82	0.90
- Loose cross-validation (IT)	3.03	<0.001	0.07	0.89	0.93	0.91	0.81	0.86
- Loose cross-validation (SE)	3.00	<0.001	0.07	0.89	0.93	0.91	0.81	0.86
- Factor structure equivalence	3.01	<0.001	0.05	0.89	0.93	0.91	0.81	0.86
- Full factor loading equivalence	3.00	<0.001	0.05	0.88	0.92	0.91	0.84	0.86
- Partial factor loading equivalence	2.99	<0.001	0.05	0.89	0.93	0.92	0.82	0.86
- Structural covariance equivalence	3.20	<0.001	0.05	0.87	0.91	0.91	0.85	0.85
- Error variance equivalence	3.70	<0.001	0.05	0.85	0.89	0.89	0.85	0.83
- CRITERION	*<5.00*	*<0.001*	*≤0.08*	*>0.80*	*≥0.80*	*≥0.80*	*≥0.50*	*>0.80*

Construct validity	**Convergent validity**			**Discriminant validity ***			
	Factor loadings (range)	Compo-site Reliability	Average Variance Extracted	1 Social	2 Health	3 Econo-my	4 Environ-ment
1 Social	0.70–0.87	0.86	0.56	**0.75**	0.62	0.69	0.78
2 Health	0.63–0.76	0.72	0.48	0.53	**0.69**	0.65	0.80
3 Economy	0.59–0.80	0.77	0.51	0.60	0.53	**0.71**	0.67
4 Environment	0.58–0.77	0.76	0.50	0.68	0.66	0.55	**0.71**
- CRITERION	*>0.50*	*>0.60*	*>0.40*	*<0.75*	*<0.69/ ≤0.85*	*<0.71/ ≤0.85*	*≤0.85*

** For discriminant validity, Pearson correlations are significant at the 0.01 level (2-tailed). HTMT is shown on the upper diagonal (≤0.85), Fornell-Larcker criterion on the lower diagonal and comparisons with square root of AVE are in bold numbers along the diagonal.*

Figure 7 illustrates how this study investigates all statements within each dimension, enabling a comparison of consumers' perceptions of different aspects of sustainability. The study focuses on reflective constructs, where the sustainability statements serve as indicators reflecting the underlying dimensions. This approach employs a second-order model, where the dimensions contribute to a higher-order latent construct – sustainability perception.

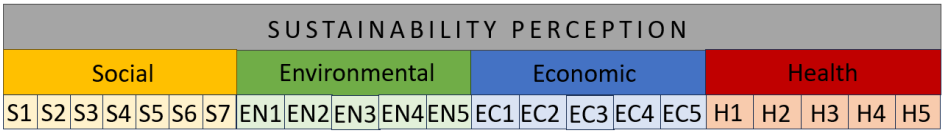

Figure 7. An illustrative representation of the Sustainability Dimensions Perception Scale (SDPS) structure, featuring 22 statements (abbreviated as S, EN, EC, H) within each of the four dimensions (social, environmental, economic, health) to assess sustainability perceptions. Full statements are provided in Appendix A5. Compiled by the author based on Article III.

Generally, consumers agreed with the sustainability statements, and thus with the dimensions, which could be attributed to the growing global awareness of sustainability in purchasing situations (Mahadeva et al., 2024). In line with the literature, which suggests that consumers most closely associate the environmental dimension with sustainability (Calanche et al., 2021; Simpson & Radford, 2012; Stancu et al., 2020), this study showed that the highest agreement with statements was under the environmental dimension (87.2% of the total sample agreed with scores ≥5 on a 7-point scale). The social dimension was a close second (86.7%), followed by the economic dimension (85.1%) and the health dimension (85.0%). Although this study focused on perception as a factor reflecting behavioural intention, another study supports that consumers are more inclined to consider the environmental dimension when making purchase decisions (Calderon-Monge et al., 2020).

When looking at Article III, it revealed five clusters of consumers. Sustainably Conscious (n = 257) and Sustainability Sceptics (n = 61) were opposed, with the first consisting of consumers who generally strongly agreed on all four dimensions, while the latter had the lowest levels of agreement. Moderate Supporters (n = 203) seemed to be in-between, with more neutral scale use for various sustainability dimensions. Furthermore, some clusters of consumers generally agreed on sustainability dimensions but leaned more or less toward specific dimensions. For example, Green Health Advocates (n = 253) agreed more with health and environmental dimensions and less with economic dimension, whereas Health Neutralists (n = 152) tended to agree less often with health statements.

It is important to note that literature suggests sustainability dimensions are often interconnected (Berglund & Gericke, 2022; Shmelev et al., 2023; Szetey et al., 2023). For example, Berglund & Gericke's (2022) focus group interviews with Swedish upper secondary students (ages 18–19) highlight the links between the environmental, social, and economic dimensions of sustainable development. Students discuss how improving quality of life (social) can lead to higher consumption (economic), but increased production (economic) may negatively impact the environment (environmental), and economic growth could be unevenly distributed (social). As consumers were clustered into five groups in current thesis, the interconnections may also vary. Sustainability Conscious individuals, who agreed strongly with all dimensions, may have recognized these interconnections between all the dimensions. For example, strong environmental concerns

often extend to other sustainability dimensions (Stancu et al., 2020). Conversely, Sustainability Sceptics, who show the lowest agreement across all dimensions, may be sceptical of sustainability claims due to confusion with sustainability messaging (Gleim et al., 2019). However, even if a consumer is less interested in one dimension, such as the economic dimension, they may still be sustainability-oriented if they place more emphasis on other dimensions, such as health and environmental, as seen in groups like Green Health Advocates.

Article III also examined which of the sustainability dimensions were more strongly associated with a particular demographic group. For example, omnivores, men and Swedes were more often among Sustainability Sceptics compared to Sustainability Conscious and Green Health Advocates. First, there was overall a high agreement in all sustainability dimensions among diet-conscious. It is possible that diet-conscious (limited or no consumption of AB foods), i.e. flexitarians, vegetarians, vegans compared to omnivores (with no restrictions on AB foods), are generally more aware of various sustainability issues. The overall understanding that PB alternatives are more sustainable was significantly more likely among diet-conscious, as shown in Article IV, whereas AB alternatives were perceived as the most sustainable and significantly more likely among omnivores. Previous studies have also pointed out the importance of environmental, health and social aspects in motivating the consumption of PB products (Fehér et al., 2020; Graça et al., 2019; Haas et al., 2019; Pointke, Ohlau, et al., 2022).

Secondly, Article III showed that women differed from men the most in the social dimension. Previous research shows that females are often more pro-active in various sustainability topics, for example, making environmental (Kawgan-Kagan, 2020) and societal (Yildirim, 2020) decisions. Article IV also confirmed that men were significantly more likely to perceive AB products as more sustainable compared to PB alternatives, which may hint that women are considering various sustainability concerns associated with AB protein production.

Thirdly, Article III demonstrated that Italians agreed more with the sustainability statements compared to Swedes, with the economic and health aspects showing the most differentiation. As discussed in the paper, it could be related to their past personal experience (e.g. more financial institutions in Italy). Further, it could be that Swedes perceiving AB milk more often as the most sustainable (Article IV) is related to the cultural experience of consuming more AB proteins from dairy compared to the Mediterranean diet (de Boer et al., 2006). On the other hand, Italians were more likely to view local labels and cardboard packaging as sustainable for milk and PB alternatives compared to organic/Fair Trade and recycled plastic, indicating a prioritisation of packaging. The higher economic and health dimensions of Italians in Article III may be linked to these packaging aspects.

Another demographic characteristic that appeared to differentiate consumer perceptions of sustainability was age. Article III identified the Health Neutralists cluster, which had the highest proportion of 18–34-year-olds. This suggests that although younger consumers are relatively aware of different dimensions of sustainability (lowest share of young consumers among Sustainability Sceptics), the importance of health issues seems to increase with age. This also confirms previous findings that older consumers shift towards vegetarianism often for health reasons, while younger consumers do so due to moral and environmental concerns (Pribis et al., 2010). The trend towards lower scores on the health dimension may also explain why younger consumers scored slightly lower overall, i.e. Sustainably Conscious had the lowest number of

18–34-year-olds. Thus, while younger consumers perceived AB proteins as significantly less sustainable (Article IV), indicating greater awareness of the sustainability issues associated with AB proteins, they were less influenced by the health dimension.

Although the discussion here is based solely on consumer perceptions of sustainability as behavioural intention, there appear to be similarities with behavioural research that explore multiple dimensions. For example, the Sustainably Conscious cluster (Article III), which showed the highest agreement across all dimensions, aligns with behavioural research by Buerke et al. (2017) suggesting that consumers who value sustainability tend act more sustainably. Additionally, their sustainability values help them become more aware of how their actions impact sustainability, further promoting sustainable behaviour. Behavioural studies also confirm similar demographic patterns related to sustainable perceptions. For instance, studies on German consumers showed that women (compared to men), middle-aged individuals (compared to those under 35), and well-educated consumers (graduate degree compared to high school or less) are more likely to purchase environmentally and socially sustainable products (Mohr & Schlich, 2016). Similarly, the Article III on sustainability perception suggests that women tend to perceive sustainability dimensions at a higher level than men, whereas consumers aged 35 and older are more likely to be part of the Sustainably Conscious cluster. Therefore, these sustainability perceptions can influence behaviour, as suggested by existing studies. This suggests that the model holds in real-life environments as well.

3.4 Multidimensional perception of sustainability in the context of milk and plant-based beverages

Overall, participants in Article IV perceived raw material as the most important sustainability factor compared to packaging, storage conditions and labels. However, the importance of the raw material was seen higher in the burger category than for the milk category (37% and 25%, respectively). This confirms that sustainability perception varies by food category (Sánchez-Bravo et al., 2020). Further, the PB raw material was seen as more sustainable in the burger category compared to the AB option, with a less distinctive difference for the milk category. This demonstrates that the perception of a sustainable product can be varied depending on the product category. For instance, for milk products, consumers are less critical about certain sustainability issues than with burgers. Similarly to the previous article, Article IV exposed five consumer segments. However, the clusters were drawn up based on the conjoint study, considering the importance of different product characteristics for sustainability. Clusters for the milk category were highly similar to the burger category, showing that even though dimensional differences may be in the perception of various product groups, consumers in both groups selected products similarly based on their perceptions of sustainability.

Cluster PF (‘Plant-based food’; n = 107) in Article IV consisted of consumers who perceived raw material as the most important for the sustainability of milk products and PB alternatives (54%). Further, PB beverages were seen as the most important compared to AB. A significantly strong positive correlation for PB was shown with the social dimension, but also a moderate positive correlation with the environmental and health dimensions. Similarly, cluster AF (‘Animal-based food’; n = 138) prioritised raw material for milk (58%), but chose AB more, which was the opposite for the PF cluster. This correlated negatively with social, environmental and health dimensions.

Cluster LL ('Local label'; n = 95) consisted of consumers who more likely tended to perceive labels as the most important for milk and PB alternatives (52%). Local label was considered as more important for sustainability than for organic or Fair Trade. It seems that the local label showed a moderate negative correlation with economic and social dimensions, indicating that they do not see that local is a more economically and socially better choice, but rather it could be related to other aspects such as other sustainability dimensions or less trust in organic/Fair Trade. Although storage condition was not prioritised by any of the clusters, LL consumers were the only ones for who the storing aspect was the second most important factor (27%), with a shift towards ambient conditions. Moderate positive correlation with health, environment and economic dimensions could be related to the perception of a safer (due to sterilisation), less energy-consuming (during storage or transportation) and more affordable product. However, the preference between ambient and refrigerated milk products could also be dependent on specific cultural habits (Liem et al., 2016; Perkins & Deeth, 2001).

Similarly to LL, cluster LI ('Label importance'; n = 110) tended to prioritise labels the most in the context of sustainability (35%). However, in this case, the utility scores did not show a clear distinction between local, organic or Fair Trade. It seems again that other factors could have been influencing the consumers in cluster LI. For example, consumers may be confused in their choices as sustainability is a diffuse term with varied understandings in labels (Grunert et al., 2014) as well as a lack of regulation on various sustainability labels (Rossi & Rivetti, 2023). Additionally, there may be a mixture of organic or Fair Trade consumers also being open to localness when the organic/Fair Trade is not made available (Denver & Jensen, 2014; Onozaka & McFadden, 2011).

Cluster CC ('Cardboard container'; n = 150) consumers tended to see packaging material as the most important for milk products and alternatives (60%). Further, they perceived cardboard containers as more sustainable compared to recycled plastic. It seemed that this was related to a moderate positive correlation with the environmental and social dimensions. While the environmental impact of cardboard containers is supported by existing literature (Bernstad Saraiva et al., 2016; Otto et al., 2021), the association with the social aspect requires further study (Lau & Wong, 2024; Lewis et al., 2010).

It is important to note that real-life behaviour may be more complex than just these factors (i.e. product characteristics) and their association with the sustainability dimensions. However, behavioural studies suggest similar findings, indicating that consumers are more likely to choose cardboard packaging (Orzan et al., 2018), local, organic, and Fair Trade labelled products, with a particular preference for local products (Blanco-Penedo et al., 2021), and more PB foods (Blanco-Penedo et al., 2021; Park & Namkung, 2024) for various sustainability reasons. However, even when sustainability is considered in purchase decisions, consumers may still make less sustainable choices, as they often rely more on emotions than on facts when evaluating products, as demonstrated in packaging decisions by Otto et al., 2021.

3.5 General discussion

For a comprehensive overview of the main results, please refer to Table 3 on the next page.

Table 3. Overview of the findings for RQ 1-4. Compiled by the author.

Research question	Response based on research findings
RQ1: What is the current market situation of PB beverages in terms of sensory aspects?	• Overall PB beverage choice is wide, but limited selection in specific raw material categories. • PB beverages were sensory-distinguishable based on their raw material. • Sensory nuances among the same category may differ (e.g. nuttiness in coconut versus hazelnut). • Sensory nuances among the same raw material may differ. • PB beverages overall often associated with a dark appearance, watery texture, and sweet and astringent taste. • Nut-based beverages tended to be the most dairy-like. • Certain sensory attributes were linked to volatile compounds that production and storage conditions can influence.
RQ2: How is the bitterness of PB substances, prevalent in PB beverages, perceived by different consumers?	• Bitter perception of specific compounds can be very varied and did not correlate with specific bitter standards. • The pea-based sample was overall perceived as more bitter than the oat-based sample. • Overall bitterness perception was not significantly influenced by diet habits. • Significantly more omnivores were in the 'high' bitterness group for peas than vegans and vegetarians. • Oat-based sample bitterness was correlated to the bitterness of fatty acids.
RQ3: How do different consumer segments perceive sustainability across various dimensions?	• Participants agreed with the environmental dimension statements the most. • Diet-conscious generally rated the importance of various dimensions of sustainability higher than omnivores. • Women evaluated the importance of various dimensions (esp. social) of sustainability higher than men. • Italians evaluated the importance of various dimensions (esp. economic, health) of sustainability higher than Swedes. • Younger consumers (aged 18–34) evaluated the importance of health dimension lower than older consumers. • Diet-conscious and younger consumers more often associated PB beverages with sustainability.
RQ4: How is sustainability perceived in the context of PB beverages?	• Dimensional perception of product characteristics differed for product categories (milk vs. burger), but consumer segments were overall similar. • Food raw material was the most important factor in the perception of sustainability overall. • PB perceived as the most sustainable raw material associated with social, environmental, and health dimensions, while AB preferers scored lower in these. • Local label was seen as most sustainable label but less linked to social and economic dimensions. • Cardboard containers viewed as most sustainable packaging, associated with environmental and social dimensions.

Findings seemed to confirm the previous perception of consumers of having a poor variation of PB alternative products (Orkla Eesti, 2023; ProVeg International, 2020). Fortunately, as the study was completed in early 2020 (Article I published in 2021), the market situation has likely improved. It can be assumed that, alongside the global growth of the PB beverage market (Mordor Intelligence, 2025), the selection of such products in local Estonian stores has also expanded. For example, during the study, soy samples were the only legume-based options available in Estonia, whereas today, pea-based beverages from brands like Vly, Sproud, Tiptoh are now also available. Similarly, the global pea beverage market is expected to grow by 10.4% from 2024 to 2034 (Future Market Insights, 2024). In addition, Estonian producers have started offering their own oat-based beverages, such as Deary (*Esimene taimne jook…*, 2020), Jane Kaerajook (Soopan, 2021) and Yook (Kenk, 2024). A similar trend is evident in the US market, where sales of oat and pea beverages have increased, while the popularity of more common categories such as almond, soy, and coconut milk has declined (Food Navigator USA, 2022). Furthermore, market reports encourage product developers to explore alternative, less commonly used plant sources such as quinoa, flaxseed, oat (Predence Research, 2024). Despite the expanding market, more recent studies continue to highlight the issue of off-flavours in various PB alternatives (Mekanna et al., 2024), including bitterness (Moss et al., 2022; Pointke, Albrecht, et al., 2022). Additionally, some raw materials, such as pseudocereals, still occupy a small market share despite their great potential (Li et al., 2025). Therefore, these issues remain unresolved in the market.

Another aspect that is often addressed is that the sensory profile of PB alternatives such as PB beverages should be similar to conventional AB products (Giacalone et al., 2022; Oduro et al., 2021; Pua et al., 2022). This study (Article I) discovered that nut-based beverages tended to be most dairy-like according to sensory analysis. This may be related to the higher fat content of nut-based beverages, which gives it a fuller body and an improved mouthfeel (Vaikma, 2023; Yao et al., 2022), as well as helping the stability of the PB solution (Silva et al., 2020; Yao et al., 2022) and taste/flavour release during eating (Chung et al., 2003; Linforth et al., 2010; Vaikma, 2023). Another question is whether the naturally occurring flavour nuances of a particular PB material need to be hindered at all but rather embraced to obtain a unique PB product (Moss et al., 2023; Short et al., 2021). For instance, using heat treatment could be used to increase roastiness in some nut-based beverages (Article I), e.g. pyrazine compounds in hazelnut beverages. These different types of product concepts – imitators and differentiators – are likely designed for two different target groups with varying priorities (Giacalone et al., 2022; Moss et al., 2023). For example, PB and non-PB consumers tend to have varied opinions and expectations on PB alternatives (Beacom et al., 2021). In the case of PB yoghurts, research involving dairy yoghurt consumers revealed a preference for dairy-like sensory properties over PB characteristics (Greis et al., 2023), indicating that these consumers align with the imitator group. Similarly, a study evaluating 18 PB beverages revealed that soy-based options were preferred for their closer resemblance to cow's milk in taste and nutritional profile, while frequent consumers of PB beverages tended to appreciate flavours such as nutty, coconut, and cereal (Jaeger, Dupas de Matos, et al., 2024). Even for PB meat alternatives, vegans and vegetarians may react negatively to products that closely resemble meat but are generally less demanding in sensory evaluations compared to omnivores (Giezenaar et al., 2024), suggesting that they might align better with the differentiator group. Thus, I suggest (**S1**) that dietary habits influence the expectation of whether a PB alternative should mimic a conventional AB product or be a unique PB product on its own. On one

hand, AB consumers (such as omnivores) expect more similarities to conventional products since PB alternatives aim to be transition products (Flint et al., 2023; Lawrence et al., 2023; McClements & Grossmann, 2021). On the other hand, PB consumers (such as diet-conscious) may be more open to unique products which could be further tested using tools like the Food Neophobia Scale.

Regardless of the expectations, bitterness is still a common issue for consumers. Knowing that PB alternative acceptability is often inhibited by bitterness (McClements & Grossmann, 2021; Moss et al., 2022), it offers a serious challenge for the producers. As discussed, various compounds (e.g. dimethyl sulphide in Article I, fatty acids in Article II) can induce bitterness but are also influenced by the technical and storage conditions, altering the final sensory profile. These aspects need to be considered already in the product development processes. However, there may be some variance due to individual experience, as the study (Article II) demonstrated bitterness being more often perceived on a high level among omnivores (although no significant influence on overall bitterness perception). Since sensory perception is individually varied, PB alternative development needs to adopt a more targeted market-oriented approach in certain situations (Beacom et al., 2021, 2022; Giacalone et al., 2022; Nicolás Saraco & Blaxland, 2020; Soukoulis, 2023). It seems that consumers' perception of bitterness in PB alternatives is predominantly influenced by the raw material rather than overall variations in individual sensitivity among consumers (**S2**). While pea-based and oat-based samples both tend to have various bitter compounds, consumers were less likely to detect bitterness in oat-based samples (Article II). This raises the question of whether changes in the production process to alter the sensory profile of oat-based beverages are equally crucial. For pea-based beverages, bitterness sensitivity tends to be more consistent across consumers, making bitterness a greater challenge for acceptability. However, this does not imply that bitterness is irrelevant for oat-based products, as some consumers remain highly sensitive to it. Instead, it highlights the need for targeted product development strategies that account for these differences in consumer preferences even more.

Improved sensory profiles alone are not enough to encourage consumers to increase their consumption of PB alternatives. As mentioned by Giacalone et al. (2022), a wide spectrum of factors (such as costs and awareness) associated with the acceptance of PB products should be acknowledged. The current study investigated various sustainability dimension perceptions as PB alternative consumption is often motivated by various sustainability concerns (Fehér et al., 2020; Graça et al., 2019; Haas et al., 2019; Pointke, Ohlau, et al., 2022). This study also confirmed a previous study that demographical factors (Article III, IV) and food category (Article IV) can affect sustainability perception (Sánchez-Bravo et al., 2020), but it was done specifically in the context of PB beverages. Further, the perception of sustainability is not constant for even an individual. Research indicates that there is a generational shift towards PB alternatives, contributing to the increasing market. According to a global study (n = 29,292) conducted in 31 countries (EAT & GlobeScan, 2022), at least 25% of younger respondents (Gen Z and Millennials) follow a PB diet compared to 18% of older respondents (Baby Boomers), and at least 40% of younger respondents express interest in a PB diet compared to 28% of older respondents. Furthermore, 42% of total respondents strongly considered adopting a PB diet over meat consumption. However, although younger consumers are generally more aware of and interested in sustainability (EY & JA Worldwide, 2023; Nichols & Holt, 2023), investigating consumer segments in the current study hinted that the importance of various dimensions may shift with age. Specifically, younger respondents (aged 18–34)

associated AB products less often with sustainability (Article IV), suggesting that the importance of various sustainability aspects for the consumption of PB alternatives can also change with age. Given that younger consumers prioritise the health dimension less than older consumers (Article III) and similar findings can be found regarding vegetarianism (Pribis et al., 2010), I suggest that the motivation for consuming PB alternatives shifts over time. Older consumers are more likely to consume PB alternatives for health reasons, whereas younger consumers are more likely to consume PB alternatives due to social and environmental reasons (**S3**). Thus, understanding these shifts calls for a pragmatic approach for further studies.

According to Aschemann-Witzel et al. (2019), achieving sustainable development necessitates a shift in consumer demand and changes within the food sector. This involves six key aspects: 1) Promoting dietary shifts; 2) Increasing food diversity; 3) Reducing food waste; 4) Enhancing circular food systems; 5) Prioritising well-being; and 6) Coping with the climate change effects. The current study proposes that to promote a dietary shift toward sustainable options, there needs to be a balance between sensory and sustainability perception. Although this study did not focus on behaviour individually, the tripartite model of attitude suggests that the behavioural aspect is often influenced by a combination of affective (sensory perception) and cognitive (sustainability perception) components (Figures 2, 3). This research argues that higher perceptions of sustainability dimensions (degree of confidence) and lower perceptions of bitterness (degree of compromise) make consumers more likely to choose PB alternatives (**S4**). Conversely, higher perceptions of bitterness and lower recognition of sustainability benefits can act as barriers to consuming PB alternatives (Figure 4). The findings further suggest that while overall bitterness perception was not influenced by dietary habits, omnivores perceived pea bitterness more likely at a higher level (Article II), indicating that the degree of compromise may be higher for certain PB alternatives. Additionally, omnivorous consumers were most likely to be part of the Sustainability Sceptics cluster, showing less agreement with various sustainability statements (Article III). They also prioritised food raw materials as the most important factor of sustainability over packaging material, storage conditions, and labels, specifically perceiving AB products as having the most important sustainability characteristics (Article IV). Thus, the degree of confidence in the sustainability of PB alternatives is much lower among omnivores compared to diet-conscious consumers.

Moreover, the optimal balance between confidence and compromise may change over time. For instance, Pagliarini et al. (2021) showed that older adults (ages 46–60) exhibit reduced sensitivity to bitterness in PB foods. In contrast, it was shown (Article III) that the importance of the health dimension in sustainability perceptions increases with age, while Health Neutralists were more likely aged between 18 to 34. This suggests that, as age increases, less importance is placed on compromising on bitterness, while greater emphasis is placed on confidence in various sustainability dimensions (**S5**). On one hand, this shift may be attributed to physiological changes, such as the reduction in vallate and fungiform papillae discussed by Witt & Reutter (2015), which reduces the bitterness sensitivity, thus confidence level needed. On the other hand, increased awareness of the impact of lifestyle choices on health, as observed in individuals aged 40–64 compared to younger adults (Okobi et al., 2023), can increase the level of confidence needed in the health dimension. Additionally, older consumers are more interested in the nutritional and health claims of food (Cavaliere et al., 2016). Thus, this suggests that consumer perceptions of PB alternatives are dynamic over time.

There is also a possibility that the importance of balancing confidence and compromise can differ based on the motivation level. For example, a study by van Bussel et al. (2019) found that consumers who follow healthy and environmentally-conscious diets tend to consume less umami, salt, fat (linked to lower consumption of meat and poultry products) and bitter (linked to lower consumption of coffee and alcoholic beverages). These individuals also eat more vegetables and cereal products. Thus, despite this lower consumption of bitter foods, they might still be open to trying various PB alternatives. Although the conjoint study (Article IV) did not specify the types of PB materials or their taste profiles, it did indicate that individuals who strongly agree with environmental, health and social dimensions are more likely to belong to the 'Plant-based food' cluster. This suggests that if sustainability habits influence perceptions of certain tastes linked to specific food categories, it would be interesting to explore whether sustainability perceptions also affect the bitterness perception in PB alternatives. Especially considering that taste perception is heavily influenced by food habits (Hayes et al., 2013; Mennella et al., 2005; Navarro-Allende et al., 2008). Individuals who are highly motivated by sustainability may be more tolerant of bitterness in PB materials. This implies that if consumers prioritise sustainability confidence more, they may be more willing to compromise on bitterness (**S6**). This could be an interesting topic for future research, as limited studies combine both internal and external food attributes, with almost half of those focusing on 'taste and labels' (Symmank, 2019).

In general, while available literature suggests that affective and cognitive attitudes (such as perceptions of bitterness and sustainability dimensions) impact consumer behaviour as expected, this is particularly important to consider for different stakeholders. Marketing and educational communications should emphasise the cognitive aspects of sustainability to resonate with consumers, while producers should focus on the affective dimensions. Moreover, producers should incorporate cognitive considerations when selecting sustainable raw materials, methods, and other factors during product development. Given the significant socio-demographic differences, these strategies should be carefully tailored to engage specific target groups. This approach enables consumers to make more sustainable and tasty choices in the rapidly growing PB alternative market, where not all PB options are equally sustainable or sensory pleasing.

4 Conclusions

4.1 Main findings

This thesis aimed to explore the most prevalent food-internal (i.e. sensory) and food-external (i.e. sustainability) factors influencing the consumption of PB alternatives. Based on the theoretical framework, both facets should be considered holistically since affective (taste perception) and cognitive (sustainability perception) aspects influence behavioural intentions through attitudes. Further, reducing the level of compromise (in bitter taste) and increasing the level of confidence (in sustainability dimensions) can be useful to encourage individuals to consume PB alternatives more.

Four studies were conducted to investigate this topic from a multidisciplinary perspective, combining insights from the fields of food technology (sensory science) and marketing (consumer science). Four research questions were investigated (RQ1–RQ4) based on quantitative results, using various sensory analysis methods, GC/MS/O analysis, and consumer questionnaires.

Compared to milk, PB beverages have a distinct sensory profile. According to the sensory panel's observations, PB beverages were often associated with a dark appearance and a watery texture, but also with a sweet and astringent taste. This emphasises the challenging nature of developing PB beverages that consumers are open to accept as an alternative to milk. In contrast, nut-based beverages resembled dairy milk more closely in sensory characteristics. However, sensory nuances can also vary within the same category (e.g., different nut-based beverages) or even among beverages made from the same raw material (e.g., various hazelnut beverages). Therefore, it's essential to understand the specific preparation, processing, and storage needs to ensure the sensory profile meets consumer expectations.

Bitterness is an even more complex issue, as previous publications indicate that bitterness plays a crucial role in consumers' perception of sensory pleasantness. Furthermore, this study showed that bitterness perceptions vary by bitter compound and do not correlate with common bitter standards. This means bitterness cannot be directly compared across compounds and is instead influenced by factors such as individual physiology and exposure levels. When comparing two potentially sustainable raw materials – oat- and pea-based (so-called 'Feelgood' products according to Plant-Based Alternative Consumer Perception Matrix) – oat-based samples were generally perceived as less bitter than pea-based samples. Further, oat bitterness sensitivity was less common among all consumers. Thus, it can be more challenging to provide pea-based alternatives for a larger audience of consumers, while for oat-based options it is less challenging. Furthermore, oat bitterness was correlated with the perception of fatty acid bitterness, while pea bitterness might be linked to other saponins or lipids (needs to be confirmed). This means that when developing a PB beverage using these raw materials, product developers need to consider the specific characteristics of each raw material, including the species and growing environment.

Sustainability perception on the other hand is another important issue, as previous research suggests that PB alternative consumers are motivated by various sustainability reasons. This study demonstrated that the perception of sustainability can vary among consumer groups. For example, diet-conscious individuals correlate PB beverages with higher importance scores for environmental, social, and health dimensions. Conversely, omnivores place less emphasis on these aspects, and more often associate AB milk with sustainability. Further, in sensory testing, omnivores were often classified in the 'high'

bitterness perception group for pea-based samples. This suggests that omnivores may lack confidence (in sustainability), and need to compromise more (for bitterness) in order to shift towards PB alternatives. Another example was that younger consumers (18–34) prioritised health dimension less than older consumers, and they were also less likely to associate AB milk with sustainability. This means that while younger consumers are more likely to be willing to consume AB products based on higher confidence in sustainability, they also tend to consider less the health dimension of sustainability.

Sustainability perception may also differ depending on the product concept. Although the study focused mainly on the raw material and showed that perceptions of AB milk and PB alternatives were often consistent with the diet group, other product characteristics were also associated with sustainability. For example, for many consumers, labelling (especially local labels), was a determining factor in choosing a sustainable product. Products packaged in cardboard containers were another important factor prioritised by some consumers for sustainability. While this thesis highlights the need to improve PB alternatives, it is important to note that these product characteristics are not always what consumers consider when looking for more sustainable options.

4.2 Thesis contributions and implications

This subchapter discusses the various contributions of this study and their potential future implications, highlighting the focus on either food-internal or food-external factors. As a multidisciplinary study, the contributions related to food-internal aspects were primarily in the food field (sensory science), while the contributions to food-external aspects were more focused on the marketing field (consumer science). However, a few contributions successfully integrated both fields, noted as 'internal and external'. Furthermore, although the current study focused on PB beverages, the findings are likely transferable to the wider context of PB alternatives.

The thesis made the following **theoretical contributions:**

- Internal and external: Plant-Based Alternative Purchase Perception Matrix was introduced in this thesis, which was an extension of the Green Purchase Perception Matrix by Peattie (2001) in the PB alternatives context. This helps to address one of the most common food-internal and food-external factors in the consumption of PB alternatives while providing a framework for studying these aspects holistically in research.
- Food-internal: This study deepened the theoretical understanding of the food-internal advantages and disadvantages of PB beverages by identifying the key sensory attributes (Article I), i.e. the affective component. This provides sensory researchers with a comprehensive framework for interpreting the sensory experiences associated with PB products.
- Food-internal: The results of this study challenged the bitterness standards currently used in sensory analysis while demonstrating the complexity of bitterness perception by examining the compound- and individual-level differences in bitterness perception in the context of PB ingredients (Article II). This can lead to new sensory research directions as well as insights into how bitterness is perceived and measured.
- Food-external: The most common three-dimensional (i.e. social, environmental, economic) concept of sustainability was extended to a four-dimensional concept, by including a separate health dimension (Article III). In the context of

consumer goods (including food), this approach can provide researchers, practitioners, organisations and policymakers with more comprehensive insights, as health is often considered separately by consumers when making purchasing and consumption decisions.

- Food-external: The results (Article III, IV) added to the literature that sustainability perception is not common and varies by individuals and product characteristics. Thus, it highlights the importance of a multi-dimensional rather than a generalised approach to sustainability. This finding encourages researchers to investigate the diverse factors affecting sustainability perception to develop a more comprehensive understanding of these concepts, which can indirectly lead to more effective communication strategies.

As an **empirical contribution**, this study:

- Food-internal: Quantified the key volatile compounds related to the odour and taste profile of PB beverages (Article I). From the affective perspective, this is important to understand the formulation of the sensory profile of PB beverages made from various PB raw materials.
- Food-internal: The bitterness perception of selected PB compounds was measured and compared (Article II). It is important to acknowledge the technological factors that result in a particular sensory profile to be able to limit potential off-nuances (such as bitterness) and improve the sensory acceptability of PB beverages (or PB alternatives in general) in the long term.
- Food-external: Provided an initial insight into the multidimensionality of consumer perceptions by measuring differences in the importance of various sustainability statements and characteristics (Article III, IV). It is crucial to not measure only the consumer impact of their decisions (as most sustainability tools available today) but also to decipher their understanding of sustainability since it is a wide term. This understanding is crucial for identifying cognitive attitudes, which subsequently influence consumer decisions (behaviours).
- Food-external: Comparative evidence in sustainability perception across socio-demographic groups (Articles II, III, IV) highlights cognitive differences. This information is invaluable for designing educational campaigns or marketing strategies tailored to specific consumer groups that place lower priority on sustainability.

This study provided the following **methodological contributions**:

- Food-internal: In terms of sensory perception, a list of sensory terms was generated based on compiled literature on PB raw materials (Article I). This can be valuable for sensory scientists in both research and industry, as demonstrated over time. The resulting list has now been used and referenced in multiple similar studies involving sensory analysis of PB alternatives, and not only PB beverages.
- Food-internal: In addition, this study (Article I) explored the RATA method for market mapping purposes in the field of sensory analysis. Results confirmed that this specific sensory technique can be applied to explore the sensory perception of a large set of samples for market mapping, both for research and industry.
- Food-external: In terms of sustainability perception, a novel four-dimensional SDPS was developed and validated (Article III). This instrument was used again

in Article IV but can be used in other future studies as well. It provides a validated tool for anyone needing to quickly assess consumer perceptions on this topic, including researchers, practitioners, organizations, and policymakers.

As **practical contributions,** this thesis was able to demonstrate the following**:**

- Food-internal and food-external: It encourages food developers to be more consumer-driven during product development, considering both affective and cognitive attitudes. Perceptions of bitterness (affective) and sustainability dimensions (cognitive) can vary significantly among individuals as well as product concepts. Thus, understanding your target audience is crucial for creating a product that meets consumer expectations.
- Food-internal: Knowledge of the technological decisions that affect the formation of specific compounds altering the sensory profile (Article I), as well as individual differences in sensitivity to these compounds (Article II), should be considered by food industries and retailers. Various decisions regarding processing and storage conditions can significantly influence the final sensory profile, thus influencing the affective attitude towards the PB products.
- Food-internal: Since bitterness perception can vary among both consumers and trained sensory panels (Article I), sensory scientists in research and industry should account for these individual differences when selecting and training sensory panels for various PB products. Additionally, it may be necessary to review appropriate bitter standards in advance.
- Food-external: The perception of sustainability regarding PB products should also be considered in communication, as sustainability perception may differ by consumers (Article III, IV) and specific product characteristics (Article IV). This can further lead to more effective marketing strategies since cognitive attitudes influence the behaviour, and ultimately guiding consumers toward more sustainable choices.
- Food-external: Further, the SDPS tool developed for the multidimensional measurement of sustainability perceptions (Article III) can be used by policymakers and organisations who wish to understand the cognitive aspects of sustainability where consumers require further education.

4.3 Thesis limitations and suggestions for future research

As with any research, this thesis has certain limitations that should be addressed. First, as highlighted throughout the study, consumer perceptions of bitterness and sustainability are highly varied. This variability makes it challenging (if not impossible) to generalise consumer attitudes comprehensively. While socio-demographic variables were considered to some extent, other external factors likely influence these perceptions (as well as the resulting behaviour). From a sensory perspective, this study primarily focused on bitter taste, though other sensory modalities also contribute to overall perception. For example, Article I suggested that nut-based beverages appeared more dairy-like due to their fuller texture. However, texture perception is more complex, evolving during consumption and influencing sensory pleasantness, as shown in PB yoghurt alternatives (Greis et al., 2020). Additionally, Article I revealed correlations between odour compounds and various taste attributes, reinforcing the interconnectedness of odour and taste in shaping sensory perception (Greis et al., 2022; Noble, 1996; Small & Prescott, 2005). From a sustainability perspective, the conjoint study considered only a limited set of product characteristics

that can be important to consumers when determining which product is more sustainable. Factors such as pricing and taste were deliberately excluded to avoid differentiation based on price sensitivity or consumer preferences, rather than perception of sustainability. However, it is well-known that both price and sensory quality significantly influence consumer decisions in conjoint studies (De Pelsmaeker et al., 2013). Moreover, in real-world decision-making, interactions between product characteristics (Almli & Næs, 2018) can further impact overall perception.

Secondly, although the theoretical framework of this study is grounded in the tripartite model of attitude – which proposes that affective and cognitive components influence attitudes, and attitudes subsequently affect behaviour – an attitude-behaviour gap may still exist (Schäufele & Janssen, 2021; Yamoah & Acquaye, 2019). Even if consumers have high confidence in the sustainability of a PB product and feel little need to compromise on taste, leading to a generally positive attitude towards PB products, other factors may influence their behaviour. For instance, food neophobia (Jaeger & Giacalone, 2021; Pasqualone, 2022) or potential stigma associated with preferring PB alternatives (Aschemann-Witzel et al., 2021; Macdiarmid, 2022). While this study examined only a limited range of affective and cognitive aspects among PB alternative consumers, further behavioural research should investigate the specific factors contributing to an attitude-behaviour gap.

Thirdly, an examination was conducted on the European consumer sample and the products available in the Estonian market. It's crucial to note that consumers' perceptions of sustainability and bitterness may vary based on cultural background, an aspect that needs further consideration. Although consumers worldwide are increasingly aware of sustainability issues (Mahadeva et al., 2024), the perception on sustainability dimensions may differ significantly. Sustainability reports in developing countries focus more on social topics (e.g., education, equity, human rights), while those in developed countries focus more on environmental issues (e.g., sustainable production, value management, supply chain emissions), with minimal differences in economic topics between the two (Kvasničková Stanislavská et al., 2023). Additionally, the range of PB alternatives in Estonia is somewhat limited while new products are entering the global market each year (Mordor Intelligence, 2025; Predence Research, 2024). As a result, some promising PB alternatives, both in terms of sensory qualities and sustainability, may have been overlooked in the initial analysis.

Based on data patterns and insights, and building on previous literature, several specific topics for further investigation have been suggested for future research:

- **S1**: Dietary habits influence the expectation of whether a PB alternative should mimic a conventional AB product (for omnivores) or be a unique PB product on its own (for diet-conscious).
- **S2:** Consumers' perception of bitterness in PB alternatives is predominantly influenced by the raw material rather than overall variations in individual sensitivity among consumers.
- **S3**: Older consumers are more likely to consume PB alternatives for health reasons, whereas younger consumers are more likely to consume PB alternatives due to social and environmental reasons.
- **S4:** Higher perceptions of sustainability dimensions (degree of confidence) and lower perceptions of bitterness (degree of compromise) make consumers more likely to choose PB alternatives.

- **S5:** As age increases, less importance is placed on compromising on bitterness, while greater emphasis is placed on confidence in various sustainability dimensions.
- **S6**: If consumers prioritise sustainability confidence more, they may be more willing to compromise on bitterness.

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Abstract

Sensory and Sustainability Challenges in the Consumption of Plant-Based Alternatives: A Focus on Plant-Based Beverages

This doctoral thesis examines the perception of plant-based (PB) alternatives, focusing specifically on PB beverages, through an interdisciplinary lens combining consumer and sensory research. Market interest in these products is growing, largely driven by sustainability values such as health, the environment, and ethics. Further, sensory factors have a strong influence on consumer acceptance. Despite increasing interest, many consumers still hesitate to adopt PB alternatives due to unfamiliarity or negative associations. The aim of this study is to explore key food-internal (i.e. sensory) and food-external (i.e. sustainability) factors that shape PB beverage consumption. Previous research has often examined these factors separately, limiting a holistic understanding of their combined impact on consumer choices. However, no single factor on its own can explain consumer preferences, as it is unlikely that a 'one-size-fits-all' solution will satisfy the diverse expectations of consumers. From a sensory perspective, taste remains a critical factor, yet the specific sensory profiles of PB alternatives – particularly challenging aspects like bitterness – are still not well understood. From a sustainability perspective, most research has focused narrowly on environmental aspects, overlooking the broader range of sustainability dimensions (e.g. economic, social), especially in the context of PB alternatives. These gaps emphasize the need for a more comprehensive approach to investigating consumer perceptions of PB alternatives, considering both sensory and sustainability factors together. This approach will deepen our understanding of real food choices and provide insights for enhancing product development. This study explores this topic using PB beverages as an example, which represent the largest segment of the PB alternatives market.

For the first theme (sensory), Articles I and II have been published, while for the sustainability theme, Articles III and IV address the key topics. The overall study was structured around specific research questions (RQs), formulated as follows:

- **RQ1** What is the current market situation of PB beverages in terms of sensory aspects?
- **RQ2** How is the bitterness of PB substances, prevalent in PB beverages, perceived by different consumers?
- **RQ3** How do different consumer segments perceive sustainability across various dimensions?
- **RQ4** How is sustainability perceived in the context of PB beverages?

In Article I, '*Market mapping of plant-based milk alternatives by using sensory (RATA) and GC analysis*', the study provides an overview of the sensory profiles of 90 PB beverages available on the Estonian market as of January 2020. Using sensory analysis and gas chromatography-mass spectrometry (GC-MS), this article addresses RQ1. Furthermore, Article I also lays the groundwork for RQ2, as it explores product bitterness (among other off-flavours) and investigates potential technological causes, based on the compounds identified through the analysis.

In Article II, *'Individual differences in sensitivity to bitterness focusing on oat and pea preparations'*, the study specifically investigates bitterness sensitivity using oat and pea preparations as examples. Both trained sensory panels and untrained consumers were involved to assess individual differences in sensitivity to bitterness substances commonly

present in PB beverages, addressing RQ2. The findings highlight the complex nature of bitterness perception, emphasizing the variability in individual taste sensitivity as well as the influence of various ingredients, and underscore the significant implications for food product formulation and optimization.

In Article III, '*Unveiling the mindset: measuring consumer perception towards the dimensions of sustainability*', consumer perception of sustainability is investigated using a multidimensional approach in a consumer study. A four-dimensional sustainability model – covering environmental, health, social, and economic aspects – was developed and tested in a consumer study. This work resulted in the creation and validation of a novel questionnaire, the Sustainability Dimensions Perception Scale (SDPS), which enables researchers to observe and compare consumer perceptions toward each sustainability dimension separately. Additionally, various consumer segments based on sustainability perceptions were explored, addressing RQ3.

In Article IV, '*Consumer perceptions of sustainability towards ingredients, packaging, labelling, and storage conditions in milk, burger products, and plant-based alternatives: A study in Sweden and Italy*', the four-dimensional SDPS is taken a step further, with sustainability perceptions investigated specifically in the context of PB alternatives, addressing RQ4. Findings from the consumer study revealed that food ingredients (raw materials) were considered the most important characteristic shaping sustainability perceptions – even more so for burgers than for milk products. Moreover, consumers who identified plant-based options as more sustainable tended to show stronger agreement across various social, environmental, and health dimensions of sustainability. Consumer segments in the context of the product were further examined, providing deeper insights into how sustainability perceptions influence consumer choices, thus further addressing RQ3.

In conclusion, both food-internal and food-external studies found that raw material is one of the most significant influencers in perception of plant-based milk alternatives. In terms of taste, it strongly shapes the sensory profile, including bitterness and other vegetal nuances. Regarding sustainability, consumers most strongly associate sustainability attributes with the product's main raw ingredient, compared to other aspects such as packaging material, labelling, or storage conditions. This emphasizes that, to develop both tasty and sustainable products, it is essential to consider both sensory and sustainability factors, as they significantly influence consumer opinion. Furthermore, it highlights the importance of understanding the food-technological influences on taste, particularly bitterness, as well as the multidimensional nature of sustainability perceptions for food developers. These findings also provide valuable methodologies and practical guidance for future research on sustainability in general, as well as specifically within the context of PB alternatives.

Lühikokkuvõte

Sensoorika ja jätkusuutlikkusega seotud väljakutsed taimsete alternatiivide tarbimises taimsete jookide näitel

Käesolev doktoritöö uurib taimsete alternatiivide tajumist, keskendudes eelkõige taimsetele jookidele. Selleks kasutab töö interdistsiplinaarset lähenemist, mis ühendab tarbijauuringud sensoorika valdkonnaga. Huvi taimsete alternatiivide vastu turul kasvab jätkuvalt, mida veavad suuresti jätkusuutlikkuse väärtused nagu tervis, keskkond ja eetilisus. Lisaks avaldavad taimsete toodete omaksvõtule tugevat mõju sensoorsed tegurid. Hoolimata kasvavast huvist on paljud tarbijad taimsete alternatiivide suhtes siiski kõhklevad, kuna need on neile võõrad või tekitavad muid negatiivseid seoseid. Selle töö eesmärk on uurida peamisi toidu-siseseid (s.o sensoorseid) ja toidu-väliseid (s.o jätkusuutlikkuse) tegureid, mis kujundavad taimsete jookide tarbimist. Varasemad uuringud on sageli käsitlenud neid tegureid eraldi, piirates seeläbi terviklikku arusaama nende ühisest mõjust tarbijate valikutele. Siiski on ebatõenäoline, et üks "üldlahendus" aitaks rahuldada kõigi tarbijate erinevaid ootusi, seega tasub vaadelda tarbijate eelistuste kujunemist mõlemalt poolelt. Sensoorsest vaatenurgast on maitse jätkuvalt üks olulisemaid tegureid, kuid taimsete alternatiivide konkreetsed sensoorsed omadused (eriti keerukad mehhanismid nagu kibedus) pole veel piisavalt hästi mõistetavad. Jätkusuutlikkuse vaatenurgast on enamik uuringutest keskendunud keskkonnamõjudele, jättes kõrvale jätkusuutlikkuse teised mõõtmed (nt majanduslik, sotsiaalne), eriti taimsete alternatiivide kontekstis. Need puudused rõhutavad vajadust põhjalikuma lähenemise järele tarbijate tajude uurimiseks taimsete alternatiivide kontekstis, mis arvestaksid nii sensoorseid omadusi kui ka jätkusuutlikkust. Selline lähenemine aitab süvendada arusaamist inimeste toidueelistustest ja pakub sisendit taimsete alternatiivide täiustamiseks. Käesolev uuring vaatleb seda teemat taimsete jookide näitel, mis moodustavad taimsete alternatiivide turu suurima segmendi.

Esimest temaatikat (sensoorika) käsitlevad artiklid I ja II, samas kui jätkusuutlikkuse temaatikat katavad artiklid III ja IV. Kogu uurimustöö struktureeriti konkreetsete uurimisküsimuste (RQ) ümber, mis sõnastati järgmiselt:

- **RQ1** Mis on praegune turuolukord taimsete jookide sensoorsete omaduste osas?
- **RQ2** Kuidas tajuvad erinevad tarbijad taimsetes jookides levinud taimsete ühendite kibedust?
- **RQ3** Kuidas tajuvad erinevad tarbijasegmendid jätkusuutlikkust erinevates mõõtmetes?
- **RQ4** Kuidas tajutakse jätkusuutlikkust taimsete jookide kontekstis?

Artikkel I pealkirjaga "Taimsete piimaalternatiivide turu kaardistamine sensoorse (RATA) ja gaasikromatograafia (GC) analüüsi abil" (originaalkeeles "*Market mapping of plant-based milk alternatives by using sensory (RATA) and GC analysis*") annab ülevaate 90 Eestis turul oleva PB joogi sensoorsetest omadustest 2020. a jaanuaris. Kasutades sensoorset analüüsi ja gaasikromatograafia-massispektromeetriat (GC-MS), käsitleb artikkel 1. uurimisküsimust (RQ1). Lisaks seab artikkel I aluse 2. uurimisküsimusele (RQ2), kuna uuritakse lisaks ka toote kibedust (koos teiste kõrvalnüanssidega) ja arutletakse selle võimalikke tehnoloogilisi põhjuseid, lähtudes analüüsi käigus tuvastatud ühenditest.

Artiklis II „Individuaalsed erinevused kibedatundlikkuses kaera- ja hernepreparaatide näitel" (originaalkeeles *"Individual differences in sensitivity to bitterness focusing on oat*

and pea preparations") uuritakse inimeste kibedatundlikkust, kasutades näidetena kaera- ja hernepreparaate. Sensoorses uuringus osalesid nii koolitatud hindajad kui ka koolitamata tarbijad, et hinnata individuaalseid erinevusi tundlikkuses taimsetes jookides kibedust põhjustavate ainete vastu. Sellega käsitleb artikkel 2. uurimisküsimust (RQ2). Töö tulemused tõstavad esile kibeduse tajumise keerukust ning rõhutavad maitse-tundlikkuse individuaalset varieeruvust ning erinevate koostisosade mõju, mis omakorda rõhutavad toiduainete koostise ja optimeerimise olulisust.

Artiklis III ehk "Mõtteviisi avamine: tarbijate tajumise mõõtmine jätkusuutlikkuse mõõdete osas" (originaalkeeles "*Unveiling the mindset: measuring consumer perception towards the dimensions of sustainability*") uuritakse tarbijauuringus inimeste jätkusuutlikkuse tajumist mitmemõõtmelise lähenemise kaudu. Selleks loodi ja testiti neljamõõtmelist jätkusuutlikkuse mudelit, mis hõlmavad keskkondlikke, tervislikke, sotsiaalseid ja majanduslikke aspekte. Töö tulemusena loodi ja valideeriti uus küsimustik, Jätkusuutlikkuse mõõdete tajumise skaala ("Sustainability Dimensions Perception Scale" ehk SDPS), mis võimaldab teadlastel jälgida ja võrrelda tarbijate tajumusi iga jätkusuutlikkuse mõõtmete kohta eraldi. Lisaks uuritakse artiklis erinevaid jätkusuutlikkuse tajumisel põhinevaid tarbijasegmente, vastates nii 3. uurimisküsimusele (RQ3).

Artikkel IV pealkirjaga "Jätkusuutlikkuse tajumine koostisosade, pakendite, märgistuse ja säilitustingimuste suhtes piimas, burgeritoodetes ja taimsetes alternatiivides: uuring Rootsis ja Itaalias" (originaalkeeles "*Consumer perceptions of sustainability towards ingredients, packaging, labelling, and storage conditions in milk, burger products, and plant-based alternatives: A study in Sweden and Italy*") kitsendab eelnevalt loodud neljamõõtmelist SDPS-i veelgi, keskendudes jätkusuutlikkuse tajumisele taimsete alternatiivide kontekstis. Sellega adresseerib artikkel 4. uurimisküsimust (RQ4). Tarbijauuringu tulemused näitasid, et toidu koostisosi (põhitooraineid) peeti jätkusuutlikkuse tajumisel kõige olulisemaks – kusjuures burgerite puhul isegi rohkem kui piimatoodetel. Selgus, et tarbijad, kes pidasid taimseid alternatiive jätkusuutlikumaks, näitasid tugevamat nõusolekut erinevatele sotsiaalsetele, keskkondlikele ja tervisealastele väidetele. Lisaks uuriti edasi ka 3. uurimisküsimust (RQ3), milleks vaadeldi jätkusuutlikkuse tajumisel põhinevaid tarbijasegmente toidutoodete kontekstis, et selgitada veel paremini, kuidas jätkusuutlikkuse tajumine võib mõjutada tarbijate valikuid.

Kokkuvõttes näitasid nii toidusisesed kui ka toiduvälised uuringud, et toidu tooraine on üks olulisemaid tegureid taimsete piimaalternatiivide tajumisel. Maitse osas kujundab see tugevalt sensoorset profiili, sealhulgas kibedust ja muid taimseid nüansse. Jätkusuutlikkuse osas seostavad tarbijad jätkusuutlikkuse omadustega kõige enam just toote põhitooraine, võrreldes muude omadustega nagu pakendimaterjal, märgistus või säilitustingimused. See rõhutab, et maitsvate ja jätkusuutlike toodete arendamiseks on oluline arvestada nii sensoorseid kui ka jätkusuutlikkuse tegureid, kuna need mõjutavad oluliselt tarbijate hinnangut. Lisaks rõhutatavad tulemused toidutehnoloogiliste mõjude mõistmise olulisust maitsele – eriti kibedusele – ja jätkusuutlikkuse tajumisele toiduarenduslikus pooles arvestamiseks. Samuti pakuvad uuringu tulemused väärtuslikke metoodikaid ja praktilisi juhiseid tulevaste uuringute jaoks jätkusuutlikkuse valdkonnas ja samuti taimsete alternatiivide uurimisel.

Appendix 1

Article I

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Market mapping of plant-based milk alternatives by using sensory (RATA) and GC analysis

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ABSTRACT

It is evident that the interest in plant-based milk alternative products is increasing, although there are still difficulties with undesired sensorial properties. This study seeks to contribute to sustainable food development through a better understanding of the market situation. The objective of this study was to get a comprehensive overview of 90 plant-based beverages currently available on the Estonian market. Main focus of this research was to map the plant-based beverage market sensorially. To evaluate such a large set of samples, RATA (Rate-All-That-Apply) was explored as a method for market mapping. A wide range of products made from different raw materials was characterized. Sensory analysis was able to make some conclusions based on specific raw materials, as there was a lot of variety among different sample groups. Combining the data collected from sensory and aroma analysis (GC/MS/O) helped to further examine the effect of volatile compounds on sensory properties of various product types. Some key compounds were found in different products, including compounds that may be causing off-flavors.

Introduction

The global plant-based alternative market is continuously growing, while one of the prevailing food trends in the dairy industry is the demand for alternative plant-based products Euromonitor International (2019). The plant-based milk alternative market was valued at over $17 billion in 2018 and is projected to grow at a CAGR of 11.5% for 2023 (Markets and Markets, 2019). Plant-based dairy alternatives are not an entirely new product category as they have been part of many food cultures historically, for example, soy milk in China and horchata (tigernut milk) in Spain (Mäkinen et al., 2016). Studies show that increased adherence to a plant-based diet is often triggered by health, sustainability, and ethical motivations (Graça et al., 2019).

Plant-based milk substitutes can be classified into five groups depending on the primary component: cereal-based, legume-based, nut-based, seed-based, and pseudocereal-based (Sethi et al., 2016). It is usually prepared by grinding the raw material followed by extraction of the liquid portion and separation of coarse particles (Yadav et al., 2017). According to EU Regulation No 1308/2013, milk is „exclusively the normal mammary secretion obtained from one or more milkings without either addition thereto or extraction therefrom“. Press release No 63/17 by the Court of Justice of the European Union emphasizes that this means that plant-based products cannot be described as „milk“ products. For this reason, plant-based milk substitutes are often titled as plant-based beverages.

Plant-based beverages are often seen as environmentally friendly products as the production emits less greenhouse gases and demands less land compared to conventional dairy industry (Mäkinen et al., 2016). However, specific raw materials are associated with other shortcomings such as ecotoxicity and bee mortality (Röös et al., 2016; Wade et al., 2019), deforestation and mineral N leaching Poore and Nemecek (2018), acidification and eutrophication (Röös et al., 2016), as well as allergenic issues. In addition, plant-based beverages often have properties that are hindering the acceptance of dairy alternative products. The main issues are off-flavors (e.g. beany flavor from soy, bitterness from seeds) and poor texture (e.g. emulsion instability from high starch content) characteristics (Sethi et al., 2016; Tangyu et al., 2019). Some off-flavors are caused by volatile compounds formed from oxidation of lipids, such as hexanal and hexanol in legume-based beverages (Tangyu et al., 2019) or hexanal and pentanal in nut-based drinks (Pérez-González et al., 2015). Bitter off-taste is often related to plant phenols, flavonoids, terpenes, and glucosinolates (Tangyu et al., 2019). From the nutritional aspect, plant proteins have lower nutritional quality compared to animal-based proteins, and for this reason, these dairy substitutes are often supplemented

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with vitamins, minerals, proteins (Mäkinen et al., 2016; Tangyu et al., 2019). Supplements may, in turn, also affect the flavor of the final product.

Concerns mentioned above express the need for products that are sensorially, nutritionally, and environmentally acceptable for the consumers. The current study focused on the sensorial aspect of plant-based beverages. Sensory science is a field that applies various methods for measuring and analyzing the response to food through the senses Lawless and Heymann (2010). It is used as a tool to understand consumers' preferences and expectations of food products, including the perception of sustainable foods (Aschemann-Witzel et al., 2019). Even though the demand for plant-based alternative products is growing, there are still issues with the acceptance of these products. A step towards comprehending the consumers is to analyze the shortcomings and strengths of the products on the current market.

Projective mapping (or napping) is a rapid method that is often used to evaluate the similarities and dissimilarities of the products Lawless and Heymann (2010). However, in order to prevent palate fatigue, the recommended sample size for a session is between 10 to 20 Hopfer and Heymann (2013). All the samples should be evaluated during one session, which does not allow comparison of the results from different sessions (Ares et al., 2013). These limitations, however, can be resolved with Polarized Sensory Positioning that sets previously located reference samples ("poles") on the same plot that is used for the evaluation allowing comparability of different sessions (Ares et al., 2013). The main issue with this method is finding the appropriate reference samples that cover the present sensory space. Another limitation is that mapping in general as a technique is a non-descriptive tool. Additional methods should be set up to turn this into a descriptive evaluation, e.g. involving ultra-flash profiling that allows using adjectives for describing samples Dehlholm (2014). In this paper, the RATA method was proposed to include more samples to analyze the market thoroughly on a descriptive scale.

Rate-All-That-Apply (RATA) is a method for sensory analysis that allows participants to select terms that are relevant for the focal sample from an acknowledged list and then rate the term intensity or applicability (Ares, Bruzzone, et al., 2014). It has been used for sensory analysis for different applications, e.g. sensory profiling of wines (Franco-Luesma et al., 2016), cheese perception and acceptability in pseudo-natural setting Torri and Salini (2016), organic label influence on flavor perception of food products (Schouteten et al., 2019). RATA is a modification of Check-All-That-Apply (CATA) approach, where evaluation is performed without the rating task. Even though CATA has been widely used in consumer studies as a rapid method for analyzing large sets of samples (Vidal et al., 2018), the advantage of RATA is that it ensures better sample discrimination and configuration stability (Ares, Bruzzone, et al., 2014). However, RATA is still under-investigated as there are limited studies about the potential of this method (Vidal et al., 2018). Previous studies have shown that RATA could be a valid, accurate, and rapid addition to existing profiling methods used (Danner et al., 2018; Oppermann et al., 2017). This may also suggest that RATA is applicable for sensory mapping. Further, there are multiple studies where RATA data has been correlated with GC-MS data in order to further understand consumer's wine perception (Copper et al., 2019; Nguyen et al., 2019). This demonstrates various possibilities to use the RATA method in a market situation.

The objective of the study was to get an overview of the plant-based beverage market in Estonia, which could help to understand the sensorial landscape of this product category and the related challenges regarding sensory properties. The mapping results were correlated to GC/MS/O data to identify possible key molecules behind certain raw material aroma notes. This paper also explored the possibilities of the RATA technique by testing its applicability for sensorial market mapping. The research seeks to contribute to sustainable food production and development through a better understanding of the current market situation. This is an important topic as sensory properties hold a crucial role in the consumption of plant-based products.

Materials and methods

Samples

The study included all available unflavored plant-based non-fermented beverages on the Estonian market in the category of milk alternatives based on one raw material (not mixes of raw materials). A total of 90 beverages was available during January 2020. Among these 42% were cereal and pseudocereal-based, 41% nut-based, 16% legume-based, and 1% seed-based. Table 1 provides an overview of all the beverage types used in this study. All subsequent tables and figures use abbreviations for the sample groups as shown in the table.

Sensory analysis

For sensory mapping, the RATA method was used. The analysis was performed by a sensory panel from the Center of Food and Fermentation Technologies (Tallinn, Estonia) consisting of 10 highly trained assessors with previous experience in sensory analysis, including evaluation of plant-based dairy alternatives. The panel consisted of 1 male and 9 female participants. Panelists were aged between 24 and 41 years old, with an average age of 31 years.

The terms list was generated based on other studies (Supplementary Table 1) that included sensory analysis with similar raw materials, e.g. soy, oat, rice. A training session was carried out with representatives from each raw material category to familiarize assessors with the samples and to finalize the evaluation sheet. A total of 32 terms were included and categorized by four modalities: appearance, odor, taste, and texture. The recommended limit for the list of terms used for RATA is not clear, though it usually falls between 10 to 20 terms (Ares, Bruzzone, et al., 2014; Vidal et al., 2018). A study about sensory terms for CATA (the predecessor of RATA) emphasizes that long lists may decrease the accuracy and frequency of selection of individual terms due to tediousness, therefore the terms list should only include relevant and product characteristic terms (Jaeger et al., 2015). For mapping purposes, a longer list of terms was used. Further, the same evaluation sheet was used for all the sensory sessions to provide comparability of the results. The order of terms was varied for each assessor and each product as it is recommended by Ares, Etchemendy, et al. (2014).

Analysis was carried out in four evaluation sessions. One session lasted about 40 to 60 min. Evaluation sessions took place within two days. Assessors had at least a two-hour break between two sessions conducted on the same day. The sessions were designed based on raw material groups to reduce the convergence effect, where a highly distinguishable (different raw material) sample can reduce perceptible differences between other samples Issanchou (2018). In addition, it was decided to evaluate all samples from one raw material group in one session to ensure the comparability of beverages. Sessions were grouped as following: 1) almond beverages (26 samples), 2) oat beverages (25 samples), 3) soy beverages (14 samples) and rice beverages (11 samples) grouped separately, and 4) other plant beverages (6 coconut, 2 hazelnut, 2 cashew, 2 buckwheat, 1 hemp, 1 brazil nut, 1 quinoa grouped separately). Some product category groups were small due to the market situation during that time period. The sample size will not be enough to describe the full potential of those raw materials, however, it gives an overview of the current market situation.

Evaluation of plant beverages was conducted in a sensory room in accordance with ISO 8589:2007 requirements. Assessors evaluated the samples individually in panel booths under white light. Samples were presented in transparent 40 mL plastic cups that were coded with a three-digit random number. The order of samples followed Williams' Latin square design. All the samples were at room temperature (22 °C). Panelists were provided with spring water (Eden Springs Estonia OÜ,

Table 1
Distribution of plant-based beverages in categories according to the raw material.

Product category	Number of samples	Percentage of samples, %
Cereal & pseudocereal-based	38	42
Oat (OAT)	24	21
Rice (RICE)	11	10
Buckwheat (BCKW)	2	2
Quinoa (QUIN)	1	1
Nut-based	37	41
Almond (ALM)	26	23
Coconut (COCO)	6	5
Hazelnut (HZLN)	2	2
Cashew (CSHW)	2	2
Brazil nut (BRAZ)	1	1
Legume-based	14	16
Soy (SOY)	14	12
Seed-based	1	1
Hemp (HEMP)	1	1

Tallinn, Estonia) and unsalted water crackers (Pladis LTD, London, UK) to clean the palate between the samples. Assessors were asked to select all the terms that describe the samples and then to rate the intensity of these selected terms. RATA is often used either on a 3-point scale or a 5-point scale (Meyners et al., 2016). In the current study, the intensity was evaluated on a 5-point scale with guiding value labels (i.e. 1 = "low", 2 = "slightly low", 3 = "medium", 4 = "slightly high", 5 = "high") to provide better distinguishability in a large data set. Data from sensory sessions was acquired using RedJade (RedJade Sensory Solutions LLC, Martinez CA, USA).

Analysis of volatile compounds

Extraction of volatile compounds using HS-SPME

Volatile compounds in plant-based beverages were extracted by solid-phase microextraction (SPME). For GC-O analysis 4 mL of sample and for GC-MS analysis 1 mL of sample were added to 20 mL glass vial with a magnetic stirrer. The vials containing the sample were kept at 60 °C for 5 min. After the pre-incubation, a DVB/CAR/PDMS fiber (SPME StableFlex^{TM}, 30 μm / 50 μm, length 2 cm) was used to absorb the volatile compounds from the headspace for 40 min at 60 °C. The desorption of volatile compounds was performed afterwards into a GC injection port for 10 min either for GC-MS or GC-O analysis.

Instrumental analysis using GC-MS

Volatile compounds extracted from plant-based beverages were identified and quantified using Micromass GCT Premier gas chromatography system (Waters, Milford MA, USA) paired with CombiPAL autosampler (CTC Analytics AG, Lake Elmo MN, USA). Absorbed volatile compounds were desorbed into a GC injection port in splitless mode with a 0.75 mm internal diameter liner at 250 °C for 10 min. The column for the system used was ZB5-MS with the dimensions 30 m × 0.25 mm × 1.0 μm (Phenomenex Inc., Torrance CA, USA). Helium was used as a carrier gas in the column at a flow rate of 1.0 mL min^{-1}. The temperature program for the oven was set to ramp up 40 °C to 280 °C at a rate of 7.5 °C min^{-1} with an additional 3 min holding time on the final temperature. The total run time for the program was 35 min. Mass spectra were obtained at ionization energy of 70 eV and a scan speed of 10 scans s^{-1}, with a mass-to-charge ratio scan range of 35 to 350. Three analytical replicates for each sample were measured. Average concentrations of identified aroma compounds are found in the Supplementary Tables 2 and 3.

Non-targeted identification of volatile compounds was carried out using an identification software (MassLynx; Waters, Milford MA, USA) and calculation of experimental retention indices (RI). Experimental retention indices were calculated using the retention times of the eluting compounds normalized to the retention times of adjacent n-alkanes. Accurate identification of the compounds was verified by comparing experimental retention indices to the NIST database (US Department of Commerce, Gaithersburg MD, USA). A semi-quantitative approach against an internal standard (4-methyl-2-pentanol; 200 µg L^{-1}) was used to quantify identified volatile compounds.

Instrumental analysis using GC-O

Odor-active compounds were investigated with a gas chromatography device Agilent 7890A (Agilent Technologies Inc., Santa Clara CA, USA) combined with an ODP sniffing port (Gerstel Inc., Linthicum MD, USA) and CombiPAL autosampler (CTC Analytics AG, Lake Elmo MN, USA). Column ZB5-MS with a size of 30 m × 0.25 mm × 1.0 μm (Phenomenex Inc., Torrance CA, USA) was used with helium as a carrier gas at a flow rate of 2.0 mL min^{-1}. The temperature program consisted of three phases: 1) from 35 °C to 85 °C at the rate of 45 °C min^{-1}; 2) from 85 °C to 200 °C at the rate of 9 °C min^{-1}; 3) and from 200 °C to 280 °C at the rate of 45 °C min^{-1} with an additional holding time of final temperature for 1 min. The injector was kept at 250 °C and the total run time for the method was 16.67 min.

The gas chromatography-olfactometry was carried out by two trained assessors in two parallels. Participants were inquired to characterize the odorants leaving from the column by applying the posterior intensity method with a 5-point scale. Due to the large set of samples, only two representatives were selected from each raw material category for GC-O analysis. The selection of the samples was based on the sensory analysis selecting the samples with the highest difference in sensory perception. The aim of the GC-O analysis was to get an overview of the potential importance of volatiles detected with GC-MS in terms of sensory perspective and to find the most important volatile components in plant drinks prepared from different raw materials. This information gives further understanding which compounds identified with GC-O analysis can be perceived sensorially in odor (Supplementary Tables 4 and 5).

Statistical analysis

Data obtained from sensory analysis (RATA) and volatile compound analysis (GC-MS) were statistically analyzed and visualized using R version 4.0.2 (R Foundation for Statistical Computing, Vienna, Austria). Although the RATA method implies that only selected terms are evaluated, not selected terms were given the value of "0" as it was also done in the past research (Oppermann et al., 2017; van Eck et al., 2019). Principal component analysis (PCA) was done using "prcomp" function. Partial least squares regression (PLSR) was done using package "pls" 2.7-3, leave-one-out cross-validation was applied. Partial least squares discriminant analysis (PLS-DA) was performed with package "mixOmics" 6.11.33. Variables were scaled and centered, and variables with less than four unique values were removed. Following the example of other studies (Meyners et al., 2016; Vidal et al., 2018), Dravnieks' scores were

Table 2
The average frequency of RATA terms used to describe samples by each assessor and sample group.

Sample group	Assessor code A	B	C	D	E	F	G	H	I	J	Sample average
OAT	9.2	10.2	9.3	9.1	9.7	8.5	9.7	7.2	7.0	10.4	9.0
RICE	9.0	8.5	9.2	7.4	7.8	11.3	10.2	6.7	6.7	9.1	8.6
BCKW	9.5	11.0	5.5	7.5	10.0	10.5	10.5	7.5	8.5	9.5	9.0
QUIN	13.0	10.0	9.0	9.0	10.0	10.0	12.0	10.0	8.0	7.0	9.8
ALM	10.1	10.6	8.3	8.0	8.8	9.6	9.3	7.3	7.3	8.9	8.8
COCO	8.0	9.8	6.5	7.5	8.7	9.5	10.5	6.7	8.5	7.3	8.3
HZLN	11.5	12.5	8.5	9.5	10.5	10.0	11.5	7.5	9.0	8.0	9.9
CSHW	8.0	7.5	6.5	7.0	7.5	9.5	11.0	7.0	7.0	8.0	7.9
BRAZ	7.0	11.0	5.0	6.0	7.0	8.0	8.0	5.0	7.0	8.0	7.2
SOY	8.9	8.9	7.8	8.5	8.6	8.3	10.1	7.7	6.5	9.8	8.5
HEMP	9.0	11.0	7.0	9.0	10.0	10.0	11.0	8.0	10.0	9.0	9.4
Assessor average	9.4	9.9	8.3	8.2	8.9	9.3	9.9	7.2	7.2	9.3	

used to balance the selection frequency and intensities between participants that described a specific product with a specific term. Dravnieks' scores were calculated as a square root of the mean value of non-zero scores multiplied by the ratio of non-zero scores. Estimated marginal means and 95% confidence intervals (Table 3) suitable for unbalanced designs were calculated using package "emmeans" 1.5.4, p-values were adjusted using the multivariate t-distribution method.

Analysis regarding the RATA method such as usage of terms and intensity scale was conducted using MS Excel (Microsoft, Redmond WA, USA). The average frequency of terms used to describe samples by each assessor and sample group is shown in Table 2. For the sample average, the sum of the average frequency of terms for one raw material was divided by the count of assessors ($n = 10$). For the assessor average, the sum of the frequency of terms used to describe all samples by one assessor was divided by the count of total samples ($n = 90$). Average intensities with standard deviations from the sensory analysis are shown in Supplementary Data 6 that describe the variability of different samples and raw materials. However, these results should not be compared with figures below that have implemented other statistical methods to find complex connections between different variables.

Results

Sensory analysis

All 32 terms from the RATA list were used during the sensory analysis. The average percentage of terms used by assessors to describe plant-based beverages ranged from 20% to 33%, which is comparable with previous results in other studies (Antúnez et al., 2019; Vidal et al., 2018). As it was previously mentioned, the intention was to use the same evaluation sheet for a wide variety of beverages. Usage of different terms ranged from 3% to 81%, which demonstrates that some terms were rather product-specific. From the appearance modality, darkness (81%) and greyness (51%) were the most frequently selected terms. From odor and taste modalities, sweetness was most frequently applied (50% and 77%, respectively). Taste was also often described through astringency (51%). As taste modality contained the largest set of terms, taste terms were also the most frequently selected on average. Wateriness was the most selected term (64%) for assessing texture. In general, the most frequently used intensities were "2" (8%) and "1" (8%), followed by "3" (6%). Meaning that assessors mostly evaluated samples as "slightly low", "low" and "medium". Similarly to findings by Vidal et al. (2018), the least used scores were at the higher end of the scale. In the current study, it was namely "5" (2%) and "4" (4%). The remaining 73% were intensity values that were interpreted as "0".

Assessors used 7.2 to 9.9 different RATA terms on average for a sample. Meaning that the sensory panel selected 8.8 terms on average (25% from the total terms list) for one sample. The decision to use the same evaluation sheet for a variety of sample groups could have lowered the usage of terms. The average frequency of using different terms for various sample groups also ranged from 7.2 to 9.9, as is shown in Table 2. Hazelnut and quinoa beverages were described with most terms on average (9.9 and 9.8, respectively). Brazil nut and cashew samples were described in the least number of terms (7.2 and 7.9, respectively), which could indicate that some terms were either too specific or these samples had a less specific sensory profile. This tendency will be further examined by volatile compound analysis.

As seen in Fig. 1, the market of plant-based beverages was varying a lot and the quality of different products from the same raw material was fluctuating. As expected, the product categories were mostly distinguishable by their main component. Cereal and pseudocereal-based beverages (i.e. oat, rice, buckwheat, quinoa) were described as having cereal taste and odor. Nut-based (i.e. almond, coconut, hazelnut, cashew, brazil nut) were characterized by nutty taste and odor notes. Legume-based (i.e. soy beverages) had stronger legume taste and odor. Seed-based (i.e. hemp beverage) possessed a hay-like odor. Even though the outcome was anticipated, it was also an indicator that the sensory panel was able to distinguish the wide variety of samples.

Cereal and pseudocereal beverage category was the biggest category in this study mostly consisting of oat beverages. In addition to higher cereal notes, oat samples tended to have stronger bitterness and aftertaste intensity. There were few quinoa and buckwheat beverage samples included in the study that were somewhat similar to oat beverages by their properties but were characterized as having a sweeter taste. Rice as a cereal was rather distinct from other cereal beverages. Rice beverages tended to have a more astringent taste and could possess a hay-like odor. Cereal and pseudocereal beverages tended to have a more watery texture when compared to other product categories. Also, these products were often characterized by their darker, greener, and greyer appearance.

The second biggest category in this study was nut-based beverages that mostly consisted of almond products. These samples seemed to be most varied in sensory properties. Besides nuttiness, almond beverages may taste salty, soapy, may have a sweet or roasty odor, and may possess a thicker, lumpier texture. Coconut beverages were the most similar to almond products by having strong nutty notes and a thicker texture. Additionally, coconut samples were the most similar products within their group when compared to any other beverage group. Hazelnut beverages seemed to resemble these two product groups, however, cashew and brazil nut beverages included in the study differed from other nut beverages by stronger saltiness and umami. Interestingly, nut-based beverages tended to associate with a dairy taste more than any other product category.

In this study, the legume-based category consisted of soy beverages only. However, these products were rather similar within the group. In addition to leguminous taste and odor, soy beverages were often characterized by metallic and astringent taste, hay-like and earthy odor, and red-tinted in their appearance. Hemp beverage was the only sample

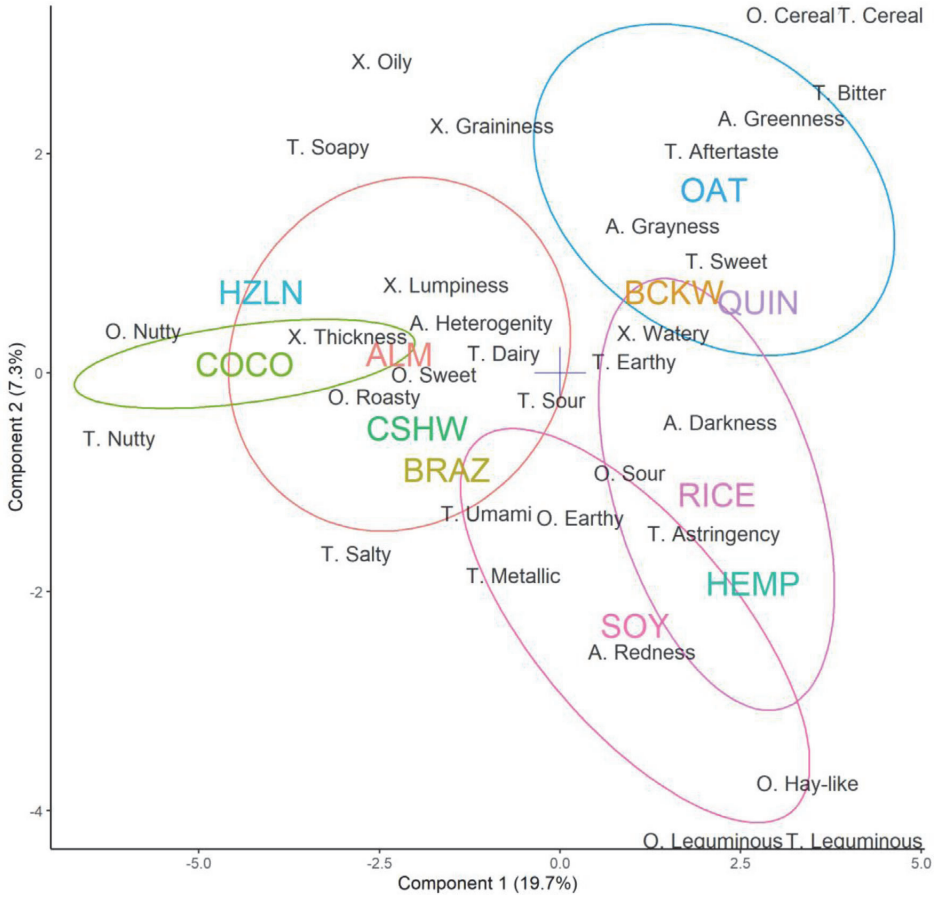

Fig. 1. PLS-DA on sensory data using Dravnieks' scores demonstrating the sensory characteristics of different raw material groups. Sample clusters are shown by 95% confidence ellipses. Abbreviations: A for appearance, O for odor, T for taste, and X for texture.

within the seed-based category and was distinguishable mostly with a hay-like odor and astringent taste.

To get more detailed information on each subset of samples, principal component analysis (PCA) analysis was conducted for raw material categories that had more than one subgroup. According to Fig. 2, all products were differentiable based on the raw material in the cereal and pseudocereal category. Oat beverages tended to be more dairy-like in taste. This is explainable as this group had a less distinctive taste profile when compared to other product groups e.g. earthy, sour, nutty, salty. However, oat beverages tended to be grainy and lumpy in texture, which in turn might have caused heterogeneity in the appearance as well. While oat beverages seemed to be green toned in their appearance, rice products tended to have more red tones. Rice beverages appeared to be sweet as well as salty, however, some products possessed an earthy and soapy taste that could be perceived as off-flavor. Some rice and oat beverages also carried sour taste, bitter taste, and strong aftertaste characteristics. Buckwheat and quinoa were included in the pseudocereal group. The number of samples from these categories was rather small, although it appears that these beverages tended to differ from oat and rice beverages by darker appearance, nutty odor, and astringent taste.

Looking at the nut category in Fig. 3, the clusters were less distinctive. Meaning that there was more variation coming from different products when compared to the specificity of raw material. Coconut drinks were distinct in the nut product category due to oily texture, sweet odor, and some even had a metallic taste. Similarly to oat beverages, coconut drinks tended to have a lumpy texture and heterogeneous appearance. Hazelnut samples were the nuttiest ones in addition to a sweet odor. Almond samples had the largest number of representative products and the profiles of the samples varied to the largest extent.

Aroma analysis

A total of 151 volatile compounds were detected with GC-MS and 98 were detected with GC-O, of which 50 compounds were detected with both methods. Determined compounds belonged to various chemical classes. According to GC-MS results (full data in Supplementary Tables 2 and 3), identified compounds were grouped as aromatic/cyclic compounds (27%), aldehydes (18%), esters (17%), ketones (13%), alcohols (9%), acids (8%), lactones (4%), and sulfur compounds (4%). When comparing specific compounds included in the supplementary table, some compounds were determined in all the raw material groups, such as hexanal, benzaldehyde, nonanal, and furan, 2-pentyl-.

Table 3 shows the average content of different volatile groups with significant differences across the raw materials. Hazelnut samples had the highest content of different acids. Hemp sample had the highest

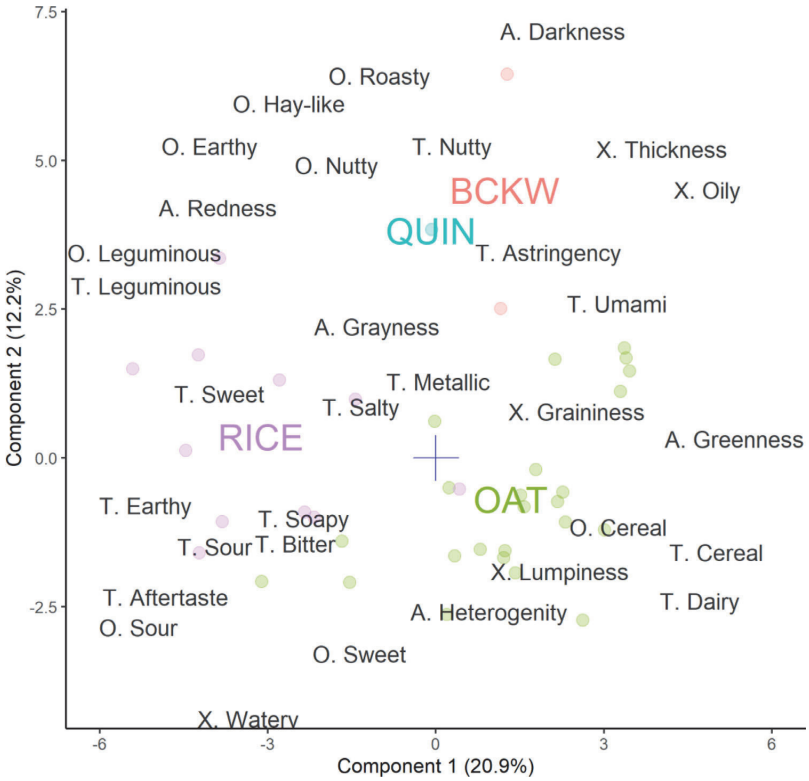

Fig. 2. PCA representing sensory characteristics for cereal and pseudocereal-based beverages based on sensory data using Dravnieks' scores. Points are the projections of the samples and the blue cross indicates the origin of the plot. Numbers in parenthesis show the variance explained by the component. Abbreviations: A for appearance, O for odor, T for taste, and X for texture.

Table 3
The average content of volatile compounds (detected with GC-MS) by chemical classes across the raw material groups. Values in a column sharing a letter are not statistically different.

	Acids		**Alcohols**		Aldehydes		Ketones	
ALM	3	a	248	b	3195	b	48	abcd
BCKW	3	abc	39	ab	283	ab	18	a
BRAZ	0	abc	14	ab	137	ab	10	ab
COCO	28	bc	4	a	1221	ab	65	bd
CSHW	7	abc	2	ab	151	ab	18	a
HEMP	0	abc	915	b	359	ab	91	cd
HZLN	38	c	68	ab	1370	ab	47	abcd
OAT	20	bc	134	a	170	a	44	abcd
QUIN	11	abc	26	ab	124	ab	8	ab
RICE	3	a	127	ab	193	a	33	ac
SOY	11	ab	263	b	129	a	61	bd
	Esters		Lactones		Aromatic/cyclic compounds		Sulfur compounds	
ALM	57	a	39	a	342	a	1	a
BCKW	19	a	0	a	55	ab	0	ab
BRAZ	3	a	2	a	74	ab	0	abc
COCO	764	b	2470	b	263	ab	0	ab
CSHW	4	a	0	a	223	ab	0	ab
HEMP	9	a	0	a	48	ab	2	abc
HZLN	38	a	10	a	384	ab	1	abc
OAT	35	a	0	a	338	a	4	c
QUIN	1	a	0	a	106	ab	0	abc
RICE	16	a	16	a	174	a	1	a
SOY	52	a	19	a	756	b	2	v

content of alcohols and ketones. Almond samples had the highest content of aldehydes. Coconut samples were characterized by the high content of esters and lactones. Soy samples had the highest content of aromatic/cyclic compounds. Oat samples had the highest amount of sulfur compounds.

Results of GC-O analysis (Supplementary Tables 4 and 5) indicated that a lot of compounds were present in multiple raw materials. The highest intensities and frequencies among all the samples were observed for 1-octen-3-ol, p-vinylguaiacol, 2-nonenal, vanillin, hexanal, p-cymenene, and (E)-linalool oxide. In some cases, different raw ma-

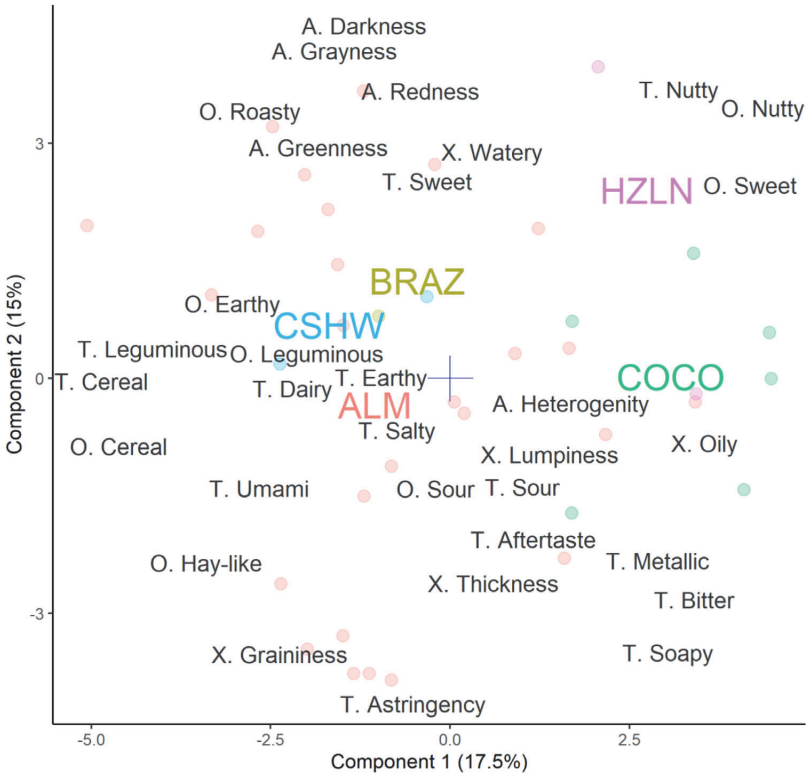

Fig. 3. PCA representing sensory characteristics for nut-based beverages based on sensory data using Dravnieks' scores. Points are the projections of the samples and the blue cross indicates the origin of the plot. Numbers in parenthesis show the variance explained by the component. Abbreviations: A for appearance, O for odor, T for taste, and X for texture.

terials were distinguished by specific key odor-active compounds that have been previously well documented. For example, benzaldehyde in almond drinks (Pérez-González et al., 2015), filbertone in hazelnut (Puchl'ová and Szolcsányi, 2018), benzaldehyde, 2-hydroxy (salicylaldehyde) in buckwheat (Starowicz et al., 2018), and different lactones in coconut (Prades et al., 2012).

Partial least square regression analysis was applied to the nut and cereal-based beverage groups which were presented with various raw materials. By combining sensory and aroma analysis, conclusions can be drawn as to which volatile compounds affect the taste and odor of specific products. Odor descriptions for volatile compounds shown in brackets were retrieved from PubChem (Kim et al., 2019). From the cereal and pseudocereal-based category, oat drinks, in general, differed from other beverages by a higher number of sulfur compounds (Table 3). However, only dimethyl sulfide (cabbage, sulfur, gasoline) was evident according to GC-O analysis (Supplementary Table 4). From the sensory aspect, this may have enhanced cereal odor and taste (Fig. 4). Buckwheat beverages were characterized by a content of benzaldehyde, 2-hydroxy- (bitter, almond-like). The same observations were discovered also with GC-O in this study, where this compound was described as buckwheat odor. In general, buckwheat samples tended to have roasty and nutty nuances according to the sensory results in the cereal and pseudocereal products category (Fig 2, Fig 4). The quinoa category could not be described since it included only one sample and specific volatile compounds could not be found because of limited results. Rice beverages were the most leguminous samples in the cereal category (Fig. 4). As rice is a cereal, it is surprising that these beverages could give leguminous notes as demonstrated in Figs. 1, 2, and 4. However, when looking at specific volatile compounds in Fig. 4, leguminous and earthy notes could be in accordance with the content of decanal (waxy, fatty) and octanoic acid, methyl ester (green, waxy).

When looking at nut-based beverages' GC data, hazelnut samples were characterized by the presence of different pyrazines (Fig. 5). Specifically, pyrazine, 2-ethyl-6-methyl (roasted) and pyrazine, 2,3-dimethyl- (walnut, almond, peanut) with the tendency to support nutty nuances. Coconut samples had the highest number of different lactones that potentially resulted in a nutty aroma, e.g. massoia lactone (creamy, sweet, coconut) and g-decalactone (sweet, coconut, buttery). Esters could have also affected coconut beverages with a soapy taste, e.g. octanoic acid, ethyl ester (waxy, fruity), decanoic acid, ethyl ester (oily, fruity), hexanoic acid, ethyl ester (waxy, fruity). Almond samples were characterized by the highest content of aldehydes according to GC-MS (Supplementary Table 3), including benzaldehyde (almond, sweet) that is characteristic to almonds. A relatively high number of alcohols were also evident in almond drinks according to GC-MS, e.g. phenylethyl alcohol (rose, honey) and 1-hexanol, 2-ethyl- (oily, sweet, floral) were identified only in almond drinks. These findings are supported by the literature, which claims that almond beverage aroma profile mostly consists of aldehydes, ketones, and alcohols (Pérez-González et al., 2015). Data from sensory analysis demonstrated that these compounds could result in a sweeter taste. Overall, almond beverages had a lot of variation sensorially and it is hard to make any conclusions based on that. Brazil nut and cashew beverages were not as distinctive as other raw materials since these samples had a lower amount of identified volatile compounds (according to GC-MS) and less specific sensory profile (ac-

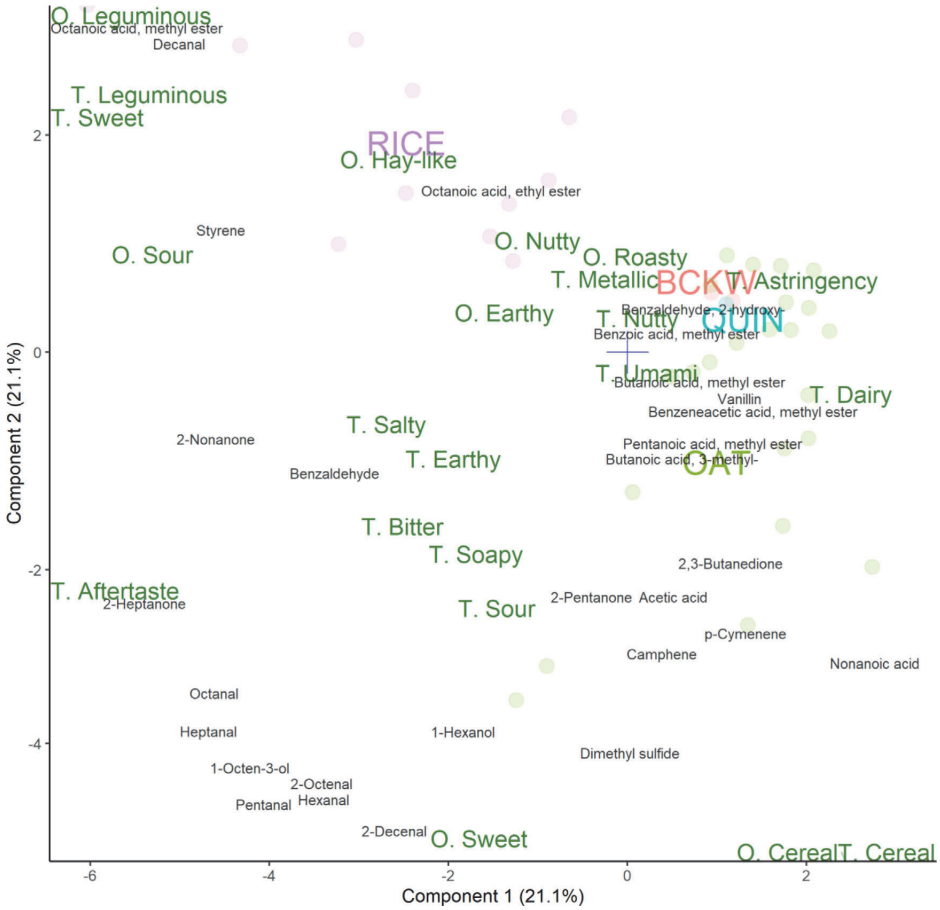

Fig. 4. Volatile compounds and sensory characteristics of different cereal and pseudocereal beverages. PLSR model on mean GC data (compounds identified with GC-MS and GC-O; black text) and mean sensory data (including only odor and taste attributes; green text) on a nonlinear scale. Abbreviations: A for appearance, O for odor, T for taste, and X for texture.

cording to sensory analysis). Moreover, the small number of samples in these sample groups made finding category-specific conclusions challenging.

According to GC-MS results (see Supplementary Table 3), soy samples had a high amount of butanoic acid, methyl ester (apple, ether) although it was found in low quantities in almost all raw materials. This compound often possesses a pungent odor, therefore, this likely may have resulted in a sour odor in soy drinks. Dimethyl sulfide (cabbage, sulfur, gasoline) was also found in soy samples, which may have caused a stronger aftertaste. Interestingly, vanillin (vanilla) was found in the highest quantity in soy beverages. One could hypothesize that flavoring with vanillin is used to hide the shortcomings in the products since these samples tend to be salty and umami, sometimes even metallic and astringent in taste.

Hemp was distinctive from other beverages by p-cymenene (spicy, phenolic, clove) as it was found in very low quantity in other samples (see Supplementary Table 2). This compound was described as phenolic and spicy in odor with GC-O analysis. From the sensory aspect, p-cymenene may increase astringency and intensify the aftertaste. Dimethyl sulfide (cabbage, sulfur, gasoline) was present in the highest quantity compared to the soy and oat samples, this could affect the astringency as well. Hemp sample tended to contain large amounts of different alcohols and aldehydes, like 1-hexanol (green, resin), pentanal (fermented), hexanal (green, fruity), and 2-octenal (green, fat) that all had green odor notes according to GC-O results. These compounds may have affected odor by causing hay-like characteristics as was described by the sensory analysis.

Discussion

Estonian market has a considerably small product range in terms of different raw materials and lack of variety as well. Thus, there is room for improvement regarding the assortment of different products and this conclusion seems to be similar to the consumers' perception in Europe. A report by ProVeg International (2020) concluded that European consumers would like to see more plant-based milk options on the shelves (40% from 6211 respondents consisting mainly of plant-based-diet followers). This means that plant-based milk alternative production and marketing should be more encouraged.

Projective mapping is a well-known tool that has been used for many years since it is rather easy to use for market assessment. Regardless of its popularity, projective mapping still has many limita-

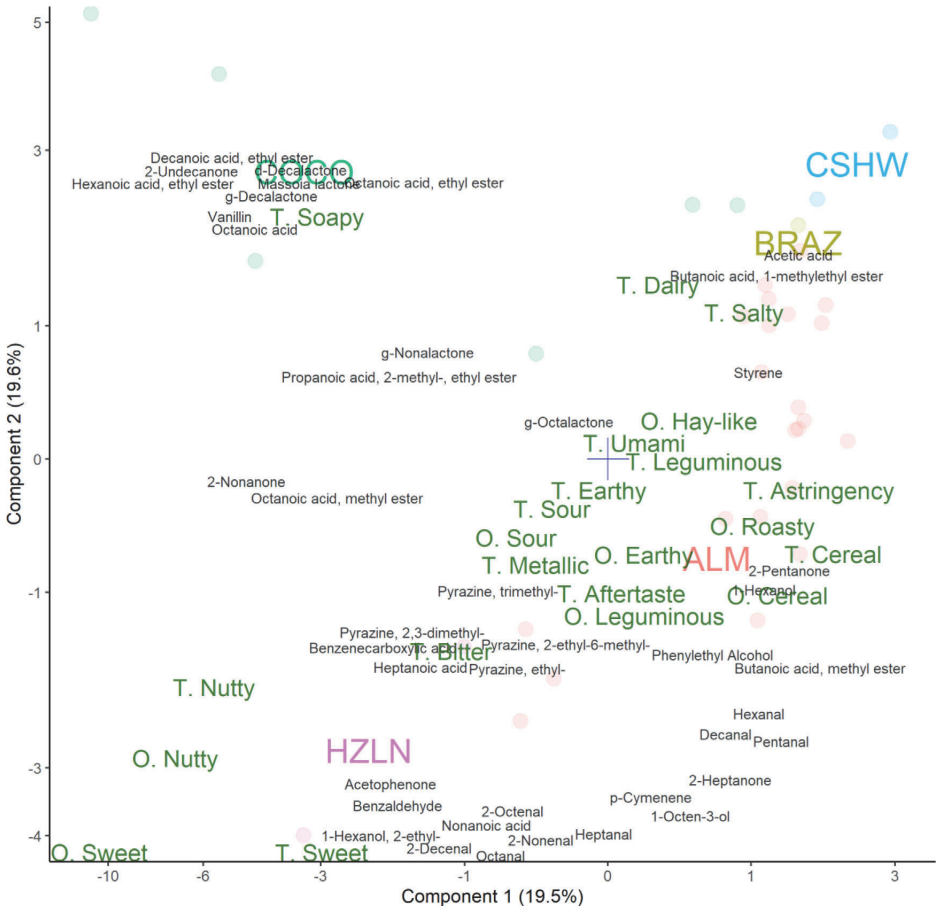

Figure 5. Volatile compounds and sensory characteristics of different nut-based beverages. PLSR model based on mean GC data (compounds identified with GC-MS and GC-O; black text) and mean sensory data (including only odor and taste attributes; green text) on a nonlinear scale. Abbreviations: A for appearance, O for odor, T for taste, and X for texture.

tions, such as restrictions on the sample size and comparability of different sessions. RATA seems to be applicable for sensory mapping of a large set of products on the market. As RATA is a relatively new technique in the sensory field, this research contributes to the growing body of literature on the possibilities with this method. Involving a large group of samples in the study provided a more comprehensive overview of the market. RATA as a technique is a faster and easier method for sensory evaluations, therefore, it can be less fatiguing in market mapping.

The imbalance of samples between the sessions occurred because the sessions were divided based on raw materials. Due to these choices, the number of samples was high in some sessions. The high number of samples was an opportunity to challenge RATA as a market mapping method. Traditionally, sensorial market analysis is done through projective mapping where the recommended sample size is over 10 Hopfer and Heymann (2013). The limit of the samples included for mapping depends on the nature of the sample and the capabilities of the sensory panel Dehlholm (2014). RATA also allows more samples to be included. For example, there are papers published with more than 10 samples per session analyzed by using RATA (Sáenz-Navajas et al., 2017; Traill et al., 2019). The current study also demonstrates that RATA is a promising method even in larger experiments.

Some studies suggest that long lists may decrease the frequency of individual terms due to fatigue (Jaeger et al., 2015). However, the frequency of using different terms was comparable to other studies (Antúnez et al., 2019; Vidal et al., 2018). Thus, the long list seemed not to decrease the frequency of terms used in this study. On average, the panelists selected 25% of the terms for one sample from a total list of 32 terms. A study by Giacalone and Hedelund (2016), which included an even longer list of 65 terms, also showed that assessors used 24% of terms per sample on average. This demonstrates that a long list of terms does not decrease the frequency of selection of different terms as it is often implied (Jaeger et al., 2015). The appropriate length for the list depends more on the experiment. Therefore, it was possible to confirm that RATA for market mapping was appropriate for this study even with the large set of samples and the long list of terms.

Some generalizations could be made about the different product types, which were also supported by the literature. A high content of lactones and esters in coconut milk has been suggested to ensure palatable flavour properties (Wang et al., 2020). Almond samples were distinctive by their high content of benzaldehyde, which is a widely known key compound in almonds (Pérez-González et al., 2015) and could give a sweeter taste for beverages as well. Benzaldehyde, 2-hydroxy- was identified in buckwheat samples as a characteristic odor

compound that is supported by the literature (Starowicz et al., 2018). Hemp, however, had the highest amount of p-cymenen that was suggested to give a stronger aftertaste. In general, different terpenes are indeed responsible for the specific hemp flavour (Aizpurua-Olaizola et al., 2016).

It also seems that heat treatment is often responsible for characteristic flavours. The presence of pyrazines in hazelnuts can be directly related to the roasting process (Alasalvar et al., 2003). Rice beverages may possess leguminous and earthy notes. This could be associated with decanal found in legumes (El Youssef et al., 2020). The concentration of that compound can be increased by the cooking process (Rodríguez-Bernaldo De Quirós et al., 2000). Oat samples had the highest number of sulfur compounds. Sulfur compounds in oats have been previously associated with heavy processing (such as high temperature) and suggested as provoking toasted cereal notes McGorrin (2019). Dimethyl sulfide content was also evident in soy samples, which has been shown to be increasing with heat treatment and to cause seaweed aroma (Morisaki et al., 2014).

One of the main issues with the acceptance of plant-based beverages as dairy alternatives is that these products often possess unwanted sensory properties. According to previous findings, the formation of hexanal, hexanol, and pentanal is often a result of lipid oxidation (Ghorbani Gorji et al., 2019; Tangyu et al., 2019; Pérez-González et al., 2015; Sanches-Silva et al., 2004). The aforementioned volatile compounds are found to induce off-flavors, such as beany and earthy flavors in legume-based drinks (Tangyu et al., 2019). In this study, mentioned compounds were identified not only in legume drinks. One of the highest amounts of these compounds (GC-MS) was found in a hemp beverage. This sample was also sensorially described (RATA) as having earthy and hay-like notes. Although this example must be interpreted with caution as there was only one product in the hemp category on the market, it seems that abovementioned compounds may induce similar flavors in other beverages as well. The current study revealed that the same compounds may elicit a stronger aftertaste in beverages.

It was challenging to further generalize the sensorial properties of different plant-based beverages made from various raw materials due to the high variability. Differences were not only evident across different product categories, but among the same product type as well. Characteristics of the final product likely depended on the origin of the raw material as well as the production technology. For instance, hazelnut samples were distinctive due to a higher average content of pyrazine, 2-ethyl-6-methyl. Marzocchi et al. (2017), however, showed that the content of pyrazine, 2-ethyl-6-methyl- is dependent on roasting temperature and time. Raw material variability should be considered in plant-based beverage production and development.

Limitations and future research

One of the main limitations of this study was the uneven number of samples in different product categories. Though the chosen samples reflected the current market situation very well, it also complicated data analysis. Some product categories, such as cereal and pseudocereal-based and nut-based consisted of a wide variety of different raw materials, while the legume-based and seed-based categories were represented by only one. Moreover, some raw materials included only one product sample, i.e. hemp, quinoa, brazil nut. Therefore, generalizing conclusions for these mentioned sample groups must be viewed with some skepticism.

Even though RATA was used for mapping a large set of products on the market with no major drawbacks, it is important to emphasize the role of the compiled terms list. Especially if deciding to use RATA for a vast set of samples. Terms included in the list should be as relevant as possible to avoid unnecessarily long lists, which can be tiring for the assessor and hinder the accuracy of the selected terms. In this study, terms that were selected more often resulted in better comparability of different samples. It was also evident that some terms could not be compared so easily. For example, heterogeneity was assessed less frequently, which means that for analysis most of the values were interpreted as zero. From the sensory aspect, this does not mean that most products lacked heterogeneity; rather, it may not have been perceived as an important feature to differentiate these products.

Additionally, the RATA list could have been improved by more precise terms. It was not surprising that cereal beverages had more cereal notes, legumes had more legume notes, etc. Raw material-specific terms could have been structured into different nuances. This was also demonstrated by the fact that while nutty was a broad concept in the sensory analysis, covering very different varieties of nuts, the aroma analysis showed that nuttiness resulted from very different compounds. Nuttiness seemed to be enhanced by a higher number of pyrazines in hazelnut drinks, by lactones in coconut samples, and by benzaldehyde in almond beverages.

Studying the formation of different compounds into specific samples was absent in this research and could be investigated more in the future. The effect of volatile compounds on sensory cognition is also a topic that needs to be addressed. The current study was able to show some of the interactions between volatile compounds and odor and taste. However, this aspect could be further studied as well as involving other sensory modalities, e.g. texture. Regarding RATA for market mapping, the applicability of this technique should be more tested by comparing the results with other approved methods. Sample group size may be reduced for cost-effectiveness, although including a variety of different product types with the same list of terms would still ensure comparability of the results. Testing RATA for mapping with other products would also provide more data to confirm these findings.

Conclusions

The present study implemented sensorial mapping of the Estonian plant-based beverage market (specifically milk alternatives). It was found that there is too little product variety as most products belonged to the same raw material groups such as oats, almonds, rice, and soy. These findings are supported by a report that European consumers feel that there should be more plant-based milk alternative choices. Products from specific raw material classes had a lot of diversity, which demonstrated that the sensorial properties of the product depend on many different aspects, for example the origin of the raw material and production technology. High temperatures in processing could induce undesirable sensory properties from specific compounds, such as decanal in rice beverages or dimethyl sulfide in soy, oat, and hemp drinks. Some flavour notes, however, could be enhanced with heat treatment. For example, nutty flavours in hazelnut beverages were induced by higher content of pyrazines. It is also important to understand the changes during shelf-life, such as the formation of hexanal, hexanol, and pentanal due to lipid oxidation. For the producers it is important to understand how these changes occur. Aroma analysis data combined with sensory analysis helped to further investigate how specific volatile compounds affected the sensory profile of the final product. For instance, benzaldehyde as a key compound in almonds may strengthen the sweet taste nuances. Terpenes, such as p-cymenen, possess a characteristic hemp odor and may elicit a stronger aftertaste in hemp beverages. Dimethyl sulfide may enhance astringency and also aftertaste. Further, some product-specific nuances can be induced by different volatile compounds. Nut-based beverages are a good example of how nuttiness was enhanced by pyrazines in hazelnut beverages, lactones in coconut beverages, and benzaldehyde in almond beverages. All these findings can be valuable for sustainable food production and development. As a methodological contribution, this study proposed RATA as a rapid method for market mapping. This method successfully allowed to test a vast set of samples compared to more conventional sensorial mapping methods with limitations on sample size.

Author contributions

CRediT authorship contribution statement. **Helen Vaikma:** conceptualization, methodology, software, validation, investigation, data curation, formal analysis, visualization, writing – original draft. **Aleksei Kaleda:** software, validation, formal analysis, visualization, writing – review and editing. **Julia Rosend:** validation, writing – review and editing. **Sirli Rosenvald:** conceptualization, methodology, validation, investigation, supervision, writing – review and editing. All authors have read and agreed to the published version of the manuscript.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.fufo.2021.100049.

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Appendix 2

Article II

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Individual differences in sensitivity to bitterness focusing on oat and pea preparations

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ABSTRACT

Growing interest in plant-based alternative products offers hope for a more sustainable future. Oat and pea are among the most potential raw materials, due to their nutritional value and their widespread growth. However, one of the key issues with the development of such products is their bitter off-taste due to ingredients like saponins, amino acids, and fatty acids. The perception of bitterness varies between compounds and depends on physiological differences among individuals, which also complicates the development of plant-based alternatives. This study aimed to investigate individual differences in bitterness sensitivity, with a particular focus on pea and oat products. Sensory evaluations (n = 12) and consumer tests (n = 100) showed that people were generally more sensitive to the bitterness of peas than oats. No statistically significant difference was observed in bitterness perception based on diet habits. Furthermore, findings demonstrated that no general standard for assessing a variety of product groups can be recommended for sensory analysis. Well-established bitter standards such as PROP, quinine, and caffeine, were not correlating with other bitter stimuli. Thus, the choice of the bitter standards to be used in sensory analysis depends on the purpose of the study and the samples included.

1. Introduction

Global issues related to environmental change have been a matter of concern for years in which the food industry holds an important role. According to a report by, "population growth of 2 billion people by 2050 will increase diet-related environmental pressures". One way to reduce the pressure is to decrease the share of crops grown for animal feed, which in turn could enhance agricultural efficiency and food availability for people (Foley et al., 2011). Since a sustainable diet involves increasing the consumption of plant-based foods (FAO and WHO, 2019), there would be greater demand for plant-based alternatives on the market. For example, the plant-based meat alternative market is estimated to increase at a compound annual growth rate (CAGR) of 7.91% from 2022 to 2027 (Mordor Intelligence, 2021b), whereas for the plant-based dairy alternative market CAGR forecast is 10.12% for the same period (Mordor Intelligence, 2021a).

Although there is a growing interest in plant-based alternatives on the market today, it is still challenging to meet consumer expectations. Consumption of alternative proteins is influenced by positive/negative emotions (Onwezen et al., 2022) or term associations (Michel et al., 2021), food neophobia (Allen, Goddard, Farmer, 2018), poor nutritional profile compared to conventional proteins (Silva et al., 2020), and accessibility in stores (Gravely and Fraser, 2018). Since taste is one of the most important drivers of food choice (Andersen et al., 2019; Boesveldt et al., 2018; De Pelsmaeker et al., 2017; Kourouniotis et al., 2016; Wedowati et al., 2020), the use of plant-based proteins can often be problematic due to their bitter aftertaste (Cosson et al., 2020; Gläser et al., 2020; Mittermeier-Kleßinger et al., 2021; Vaikma et al., 2021).

Bitterness has played an evolutionarily important role as a defense mechanism against toxin uptake (Shichida et al., 2013). Certainly, this has had a significant impact on human dietary patterns. However, bitterness does not always indicate harmfulness and may be related to other beneficial compounds as well (such as antioxidants, and phytonutrients) (Nissim et al., 2017; Shichida et al., 2013). It has been concluded that there is a variation in bitterness sensitivity between individuals and it can be related to generic genetic or specific genetic variation as well as environmental circumstances (such as diet) (Dsamou et al., 2012). The situation is further complicated by the fact that bitter compounds differ by raw material and their specific composition. Bitter off-taste in plant-based alternatives, however, can be related to various ingredients, such as glucosinolates, flavonoids, phenols, terpenoids, terpenes, mono-

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glycerides, fatty acids, peptides, and amino acids (Chigwedere et al., 2022; Gläser et al., 2020; Günther-Jordanland et al., 2016; Mittermeier-Kleßinger et al., 2021; Nissim et al., 2017; Tangyu et al., 2019).

One of the most promising raw materials for plant-based alternative producers are oats and peas. They are mainly grown in temperate regions, but can also be grown in other climates such as the Mediterranean (Canales et al., 2021; Djanaguiraman et al., 2020; Neugschwandtner et al., 2020). They also have good nutritional value, for instance, fiber and protein content (Dahl et al., 2012; Rasane et al., 2015; Sterna et al., 2016). Growing interest in pea and oat-based alternatives is also supported by the results of the Smart Protein (2021) consumer survey (n = 7578), according to which 32% of European consumers would like peas to be the main ingredient in a plant-based diet, whereas 29% would prefer oats. However, these raw plants often have issues with bitterness. Therefore, pea and oat proteins have been included in the current study together with some associated bitter compounds.

Saponins have been considered the key bitter compounds in some plant-based sources, although specific compounds may vary depending on the raw material. Pea bitterness is caused by soy saponin I and 2,3-dihydro-2,5-dihydroxy-6-methyl-4H-pyran-4-one (DDMP) saponin (Heng et al., 2006) while oats have different steroidal and furostanol saponins (Günther-Jordanland et al., 2016, 2020). Avenanthramides have previously been considered as key bitter compounds in oats (Günther-Jordanland et al., 2016), although a more recent study indicates that their relation to oat bitterness is not significant (Günther-Jordanland et al., 2020). Research has shown that lipids are also contributing to the bitterness in plant-based products. A study by Gläser et al. (2021) investigated 17 pea-protein isolates and found that linoleic acid and α-linolenic acid had the highest impact on bitter taste among lipids. These fatty acids have great activeness for the bitter taste in oat flour (Günther-Jordanland et al., 2020). In addition to fatty acids, monoglycerides have a significant impact on oat bitterness (Günther-Jordanland et al., 2020), and trihydroxyoctadecenoic acids on pea bitterness (Gläser et al., 2020). Since plant proteins and their hydrolysates provide bitter peptides and amino acids (Mittermeier-Kleßinger et al., 2021), these compounds also hold an important role in the bitterness of plant-based products. Tryptophan has been found to be the most potent amino acid stimulating bitterness (Kohl et al., 2013) found widely in various foods such as soy, oat, wheat, egg, and cheese (FoodData Central, 2019; Laffitte et al., 2016).

The development of plant-based products that are pleasant for most consumers is often difficult. Not only because bitterness is perceived differently depending on the composition of the product, but also because of individual sensitivity to bitter compounds. There are approximately 25 different T2R receptors in the human gustatory system that can be activated by various bitter compounds in different concentration ranges (Roura et al., 2015; Shichida et al., 2013). As different receptors are involved in bitter stimuli, individual differences in taste thresholds of consumers affect each person's perception of bitterness. In the sensory field, reference compounds are often used to standardize the use of scales for assessing bitterness. One of the most frequently used compounds as bitter standard are caffeine (Chigwedere et al., 2022; Czepa and Hofmann, 2004; Kobue-Lekalake et al., 2012) and quinine (Caporale et al., 2004; Nath et al., 2022; Nissim et al., 2017). Among others propylthiouracil (PROP) is similarly often used to characterize individual differences in sensitivity to bitterness (Agovi et al., 2022; Cosson et al., 2020; Tepper et al., 2001). However, sensitivity to all these compounds (PROP, quinine, and caffeine) has been shown to depend on genetic variation to some extent (Hansen et al., 2006). There have also been studies showing bitterness linked to diet habits. For example, Cliceri et al. (2018) found that PROP responsiveness was lower in the vegetarian population (compared to flexitarians and omnivores) and Mozhdehi et al. (2021) demonstrated with a female sample group, that vegetarians had a lower detection threshold for caffeine (compared to omnivores and vegans).

Consumption of plant-based alternatives is often driven by sustainability motivators. Europe's Bioeconomy Strategy encourages innovation toward sustainable food production and consumption (European Commission, 2018). There are many different approaches to improving the flavor of plant protein products. Mittermeier-Kleßinger et al. (2021) provide an overview of strategies such as fermentation or hydrolysis methods, masking bitterness with other flavors or with bitter inhibitors, post-processing by marination or seasoning, choosing "pure" protein isolates or concentrates, changing the texture to induce the applicable interaction with flavor perception, etc. Before choosing a specific treatment technique, it is important to understand which compounds cause unwanted bitterness and how important this sensation is to individual sensitivity. For example, breaking down bitter molecules may lessen the health benefits of these specific compounds in some cases (Nissim et al., 2017).

The present work aimed to investigate individual differences in various bitter stimuli. Individual sensitivities were studied from the standpoint of trained assessors as well as consumers with different diet patterns. The focus was particularly on oat and pea preparations, which often have problems with bitterness despite the high market potential of these raw materials. It was hypothesized that oat and pea have greater variability in bitterness sensitivity than the well-established bitter standards (PROP, quinine, and caffeine), which underlines the importance of sensory panel selection and the use of proper bitter standards.

2. Materials and methods

2.1. Participants

Participants in the sensory evaluations were selected from a pool of highly trained evaluators. Training and monitoring of the assessors had previously been conducted according to ISO 8586:2012. Sensory tests were conducted with 12 trained panelists (average age 31 ± 6 years), who have had previous experience in evaluating plant proteins and plant-based products. Assessors were further familiarized with the samples and the methodology in preliminary tests described in chapter 2.3.

The consumer test was conducted with 100 untrained participants (average age 32 ± 10 years, 20 males and 80 females) of whom 43 were vegans/vegetarians and 57 were omnivores/flexitarians. The sample group was not balanced in terms of age or gender, as focus was only on dietary habits. Hayes et al. (2013) discuss that habits may override genetic differences in bitterness perception. Dietary groups were allocated on the assumption that omnivores and flexitarians consume conventional foods more than vegans/vegetarians who often include plant-based alternatives in their diets. Likewise, established in the previous literature (Cliceri et al., 2018; Mozhdehi et al., 2021), flexitarians and omnivores could be more responsive to bitterness compared to vegans and vegetarians.

All participants gave written consent to take part in the experiment. Participants were informed in advance of the purpose and the procedures of the study. Participants were assured of the confidentiality of their data. Taking part in the given study was voluntary and one could withdraw from the test at any time. Participants were in good health and had no known allergy to the components.

2.2. Samples

The final list of bitter stimuli (Table 1) was selected based on a focus on specific plant preparations as well as some of the well-established bitter taste standards with chemical diversity. Unrefined organic yellow pea and whole grain oat flour were used to understand the perception of bitterness in plant-based matrices. The nutritional content of pea and oat flour is given in Table A.1 in Supplementary Material. Based on the literature on the identification of bitter compounds, fatty acid standards for corresponding plants were included. Unfortunately, due to the

Table 1
Compounds evaluated in the sensory analysis.

Compound	Supplier	Concentration (g/l)	Reference	Purpose
Caffeine (99%)	Sigma-Aldrich, Burlington MA, United States	0.392	Roura et al. (2015)	Sensory analysis
Linoleic acid (95%)	Sigma-Aldrich, Burlington MA, United States	6.65	Günther-Jordanland et al. (2020)	Sensory analysis
Linolenic acid (99%)	Sigma-Aldrich, Burlington MA, United States	1.01	Günther-Jordanland et al. (2020)	Sensory analysis
L-tryptophan	Fitness Trading, Zambrów, Poland	3	Solms (1969)	Sensory analysis
Whole grain oat flour	Tammejuure Mahetalu OÜ, Tammejuure, Estonia	65	NA	Sensory analysis and consumer test
Yellow pea flour	Tammejuure Mahetalu OÜ, Tammejuure, Estonia	65	NA	Sensory analysis and consumer test
Quinine hydrochloride dihydrate (95%)	Sigma-Aldrich, Burlington MA, United States	0.0125	Roura et al. (2015)	Sensory analysis
Propylthiouracil (PROP)	Sigma-Aldrich, Burlington MA, United States	0.0544	Tepper et al. (2001)	PROP test
Sodium chloride (NaCl)	AAS Mozõrsol, Gomeli obl., Belarus	5.8	Tepper et al. (2001)	PROP test

limited availability of plant-derived organic chemicals, saponins, monoglycerides, and trihydroxy-octadecenoic acids, were not included in the study as pure standards.

A preliminary sensory test was conducted with all samples to make sure that the given concentrations can describe differences in bitterness sensitivity between assessors and samples (described in chapter 2.3). Concentrations for the compounds were selected based on previous literature (references in Table 1). For oat and pea flour, suitable concentrations were established with the preliminary tests. According to a paper by Günther-Jordanland et al. (2020), linolenic acid and linoleic acid have very different bitter threshold concentrations. To ensure comparability of the bitterness of fatty acids, the same dose-over-threshold (DoT) factor was used for both fatty acids. The chosen concentration was based on the concentration level of linolenic acid previously detected in oat flour (Günther-Jordanland et al., 2020). The final decision on the concentrations was made based on the preliminary tests when it was confirmed that all sample solutions were perceptible at the given concentrations and fully fit the scale.

The solutions for the sensory test were prepared on the same day of the experiments using potable water (Saku Läte OÜ, Estonia). Fatty acids were emulsified in the potable water using 0.1% xanthan gum (Piprapood OÜ, Estonia) solution for equal distribution. Solutions for the PROP test were prepared the day before evaluation using distilled water and were kept at +4 °C before the evaluation.

2.3. Sensory analysis

A preliminary sensory test was conducted with 9 trained panelists, in which participants evaluated the bitterness of all samples noted in chapter 2.2. Preliminary tests also included the evaluation of other basic tastes, as studies have shown that specific bitter stimuli often include astringency and/or acidity (Chalé-Rush et al., 2007; Gläser et al., 2021; Stephan and Steinhart, 2000). However, as these were not detected at all or with very low intensity, the risk of a dumping effect (Clark and Lawless, 1994) was minimal and these additional features were excluded. Both the preliminary test and the sensory analysis were conducted using nose clips as in other research (Cosson et al., 2020; Epke et al., 2009; Higgins et al., 2021; O'Mahony, 1991; Pirc et al., 2022) to minimize the effect of interfering retronasal sensations, especially the strong flavor of oat and pea samples. For example, it has been shown that bitterness in olive oil is in co-occurrence with cis-3-hexen-1-ol in the odor profile (Caporale et al., 2004) that as a compound may also be found in plant-based dairy alternatives (Vaikma et al., 2021).

All sensory analyses were carried out by 12 trained experts at the centre for Food and Fermentation Technologies (Tallinn, Estonia) in a dedicated sensory room in compliance with ISO 8589:2007. Sensory tests were conducted following ISO 6658:2017. Panelists participated in two separate sensory tests: the PROP test and the sensory analysis (see also Table 1). First, the PROP test was conducted in a session as a classical method to study bitterness status and to investigate whether it alone could explain bitterness sensitivity. One-solution PROP test was based on the study by Tepper et al. (2001) where the taste intensity of 0.32 mmol/l of PROP and 0.1 mol/l of NaCl was evaluated on a General Labeled Magnitude Scale (gLMS). Panelists were then grouped as supertasters (PROP value $\geq$ 51), medium-tasters (51 > PROP value > 15.5) and non-tasters (PROP value $\leq$ 15.1).

Secondly, samples for sensory analysis were evaluated in two parallels, in a total of four sessions. Sessions were conducted within two days. Two sessions were conducted on one day, with 45-minute breaks between. The assessments on each day were carried out at the same time of day to minimize variation in sensitivity. All sessions consisted of 5 samples and the assessment took about 10–15 min in total. The assessors were asked to evaluate the bitterness of each sample. The working linear scale was established at 0–9, where "0" represents no stimulus, "1" very low, "5" medium, and "9" very strong.

Samples were served in 30 mL transparent cups coded with three-digit random codes. Assessors were encouraged to stir the samples before testing to reduce possible precipitation in the samples (especially for sensory analysis that included flours). All the samples were at room temperature (21–22 °C) during the evaluation. Evaluations took place as a blind test. The samples for the sensory analysis were given to assessors in different order following a Williams' Latin Square design to reduce the carry-over effect (Macfie et al., 1989). Preliminary experiments showed that quinine was generally perceived as bitter by all the assessors and therefore it was used as the first sample in each sensory test to compare the different sessions with each other. Quinine is often used as a standard in other studies as well (Caporale et al., 2004; Nath et al., 2022; Nissim et al., 2017).

Data collection was done using RedJade sensory software (RedJade Sensory Solutions LLC, Martinez CA, USA). The intensity of bitterness is a temporal stimulus, the rate of which depends on the specific compound (Higgins et al., 2021; Leach and Noble, 1986). To reduce the effect of time intensity, the time for the assessment of each sample was set at 60 s after which it was possible to mark the highest perceived intensity on the evaluation sheet. Since the intensity of bitterness can also accumulate with increased exposure, such as the number of sips (Mura et al., 2018), long breaks between samples were also encouraged. Due to the ethical and safety aspects assessors were asked to spit out all the samples. It was also important to standardize the method of intake for all participants, as research shows that swallowing a sample can increase perceived bitterness (Running and Hayes, 2017). After each sample, palate-cleansing was set to 60 s until the next sample could be evaluated. Assessors were provided with spring water, water biscuits, and pears as palate cleansers.

2.4. Consumer test

The same oat and pea flours were used for the consumer test in the same concentrations as in the sensory analysis with trained panelists.

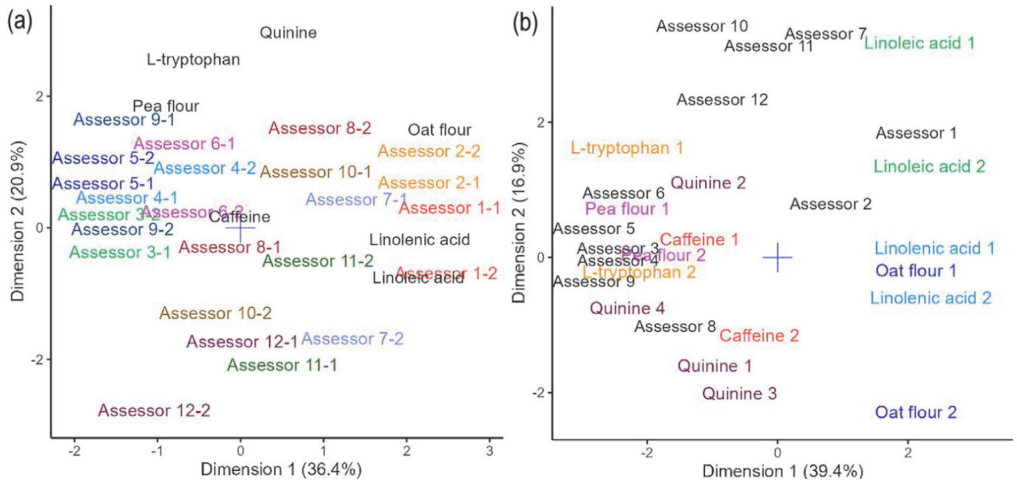

Fig. 1. PCA plot representing sensitivity to different bitter stimuli by assessors in replicate experiments (a) and by stimuli in replicate experiments (b). Numbers 1 and 2 indicate the replicate values. The numbers on the axis names indicate the variance explained by the component.

Sample preparation was done in the same way as for the sensory analysis described in chapter 2.2. The consumer tests were carried out in the same sensory room (in compliance with ISO 8589:2007) as the sensory analyses. The samples were served in plastic cups covered with a lid. Participants were instructed to shake the samples before consumption to reduce the possible precipitation. Nose clips were used during the evaluation of the samples. A scale from 0 to 9 was applied as in the sensory analysis, ranging from "none" to "very strong". The time for the assessment of each sample was set at 60 s and the participants were asked to mark the highest perceived intensity of bitterness on the scale.

2.5. Statistical analysis

Initial data analysis for sensory analysis and consumer test was conducted using MS Excel (Microsoft, Redmond WA, USA). For example, Relative standard deviation (RSD) was used to see whether the stability of different sessions for each assessor was improved by the standardization process. Similarly to other publications (Zhang et al., 2018; Zhi et al., 2016), RSD criteria for an acceptable variation was set as < 20%. PanelCheck (version 1.4.2, Nofima, Tromsø, Norway) software was used to check the performance of the panel and assessors building on the publication by Tomic et al. (2009). Panel stability and compound variation were further analyzed statistically using R version 4.2.0 (R Foundation for Statistical Computing, Vienna, Austria). Ordinations for Principal Component Analysis (PCA) were also calculated and visualized using the “prcomp” function".

Statistical analysis for the consumer test was done in R version 4.2.0 (The R Foundation for Statistical Computing, Vienna, Austria). The results were not normally distributed; thus, the Wilcoxon rank-sum test and Chi-square test of independence were used to check for statistically significant differences. Wilcoxon rank sum test was performed to see whether there would be a significant difference between the omnivore/flexitarian and vegan/vegetarian population’s sensitivity to pea and oat bitterness and whether there is a difference between the two flours. In addition, people were divided into groups based on given ratings to bitterness intensities (0–2 as low, 3–6 as medium, 7–9 as high), which was tested with Pearson’s Chi-squared. The purpose of the test was to see whether there would be statistically significant differences in the distribution of data in these bitterness groups between omnivores and vegans/vegetarians.

3. Results

3.1. Sensory analysis

3.1.1. Panel stability across sessions

It was important to minimize the possible differences coming from variations in sensitivity and scale usage across days/sessions. Since quinine was used as a reference, the results were initially standardized to the intensity of the compounds assessed in sessions against the quinine intensity for the same session. Comparing the results before and after the standardization showed that most RSD exceeded the criterion even after the standardization. Specifically, 45% of all RSD values exceeded the criterion before standardization, while this increased to 58% after standardization. It was revealed that the difference in evaluation scores across sessions was not in correlation with quinine scores, thus, the results were not standardized for further analysis. Meaning that the variations in scores were not caused by scale usage differences but instead could be related to the variations in sensitivity that might be different for each bitter stimulus.

PanelCheck was used to pre-check the performance of the panel and assessors. 3-way ANOVA confirmed that there were significant differences for bitter stimuli ($p < 0.001$), but no significant differences for the assessor effect nor replicate session effect. This was an acceptable result for this study, as the aim was not to achieve similar results, but rather to examine individual differences in the perception of bitterness. F values showed that most of the assessors were able to discriminate the samples on a significant level. Further, p*MSE (mean square error) showed that assessors were able to differentiate bitter stimuli with some variation in repeatability. The existence of large differences is supported by the explained variance shown in the PCA plots, where a total of PC1 and PC2 explained 57.3% and 56.3% of the variance (Fig. 1a and Fig. 1b accordingly). When comparing assessors (Fig. 1a), a wide variation in the sensitivity to different bitter stimuli was demonstrated. This seems to confirm that bitterness is a complex stimulus that can be perceived very differently depending on the person and the compound. Generally, the evaluation results from the parallel sessions were similar with some variation – assessors perceived bitterness largely in a similar way, regardless of the day. However, the variability of evaluation scores across replicate sessions was specific for different bitter stimuli. Pea flour had the most stable evaluation scores across sessions (Fig. 1b). The bitterness of pea flour was perceived generally with high intensity by most of

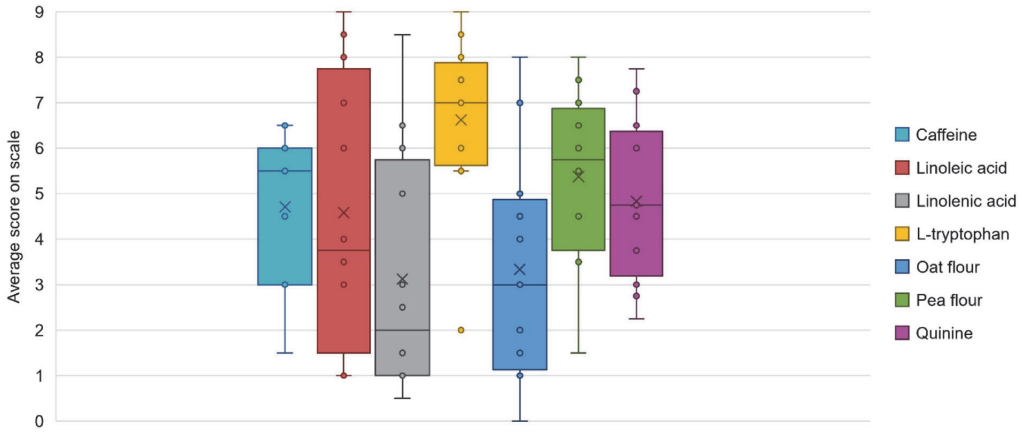

Fig. 2. Box & Whisker plot for bitterness by each stimulus. Circles and whisker endpoints indicate individual scores of assessors. The average value is marked with "X", the median is marked with a horizontal line, and whiskers indicate lower and upper quartiles.

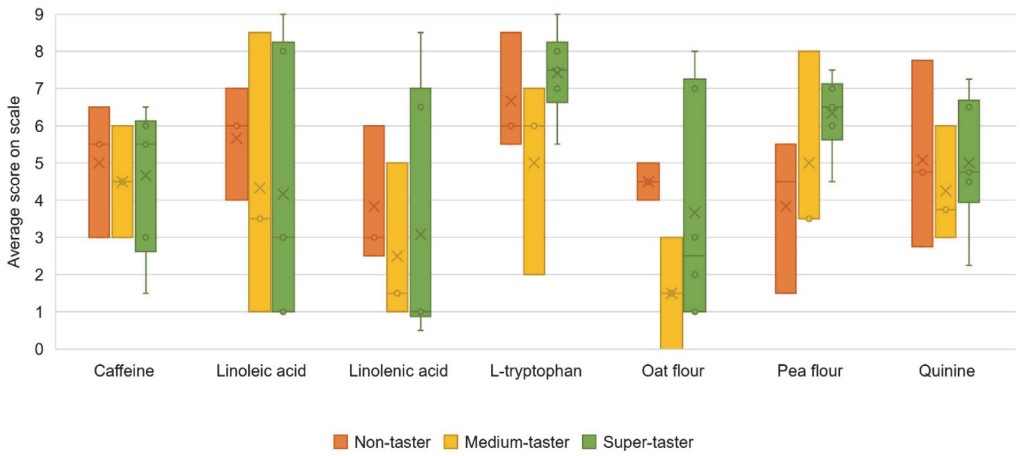

Fig. 3. Box & Whisker plot for the bitterness of compounds by PROP taster status. Circles and whisker endpoints indicate individual scores of assessors. The average value is marked with "X", the median is marked with a horizontal line, and whiskers indicate lower and upper quartiles.

the panelists. The highest variation between sessions was observed with fatty acids and oat flour.

3.2. Variation of bitterness perception for different stimuli and relationship to prop sensitivity

Fig. 2 demonstrates differences in bitterness perception by each stimulus (average scores and standard deviations for each sample and assessor can be found in Table A.2 in Supplementary Material). In general, L-tryptophan had the smallest variation of ratings among the panel, while fatty acids, oat, and pea flour had higher variations in bitterness evaluated by different assessors. This also seems to confirm the hypothesis that oat and pea bitterness has higher variability in the perception of bitterness than other well-established standards.

According to PROP test, panelists were divided into 3 groups: super-tasters (PROP value $\geq$ 51), medium-tasters (51 > PROP value > 15.5) and non-tasters (PROP value $\leq$ 15.1). The aim was to determine whether PROP taster status correlates with the sensitivity to different bitter compounds. Of the 12 panelists, 6 were categorized as super-tasters, 3 as medium tasters, and 3 as non-tasters. Fig. 3 demonstrates that there was no clear connection between compound sensitivity and PROP taster status. Only pea flour seemed to have some connection with taster status, where non-tasters evaluated bitterness as the lowest on average and super-tasters as the highest. With some compounds, the super-taster group had less variability, for instance, pea flour and L-tryptophan. Interestingly, the largest variations for super-tasters were in oat flour and fatty acid (linoleic and linolenic acid) bitterness, indicating that there may be a greater discrepancy in the bitter sensitivity of oats. Furthermore, the sensation of fatty acid bitterness was associated with an irritating mouthfeel, making it challenging to describe. Medium-tasters had the largest variations with linoleic acid, L-tryptophan, and pea flour bitterness. For non-tasters, however, quinine bitterness varied the most. Caffeine was the only bitter stimulus perceived similarly by all taster groups, as indicated by similar variability and average bitterness.

Correlations between different bitter stimuli are shown in Table A.3 in Supplementary Material. A strong association was seen between fatty acids. There was a very strong correlation (ρ = 0.95; p < 0.001) between linoleic acid and linolenic acid. Oat flour was also strongly correlated with linolenic acid (ρ = 0.61; p < 0.5) and moderately correlated (ρ = 0.48) with linoleic acid. This confirms that the fatty acids are

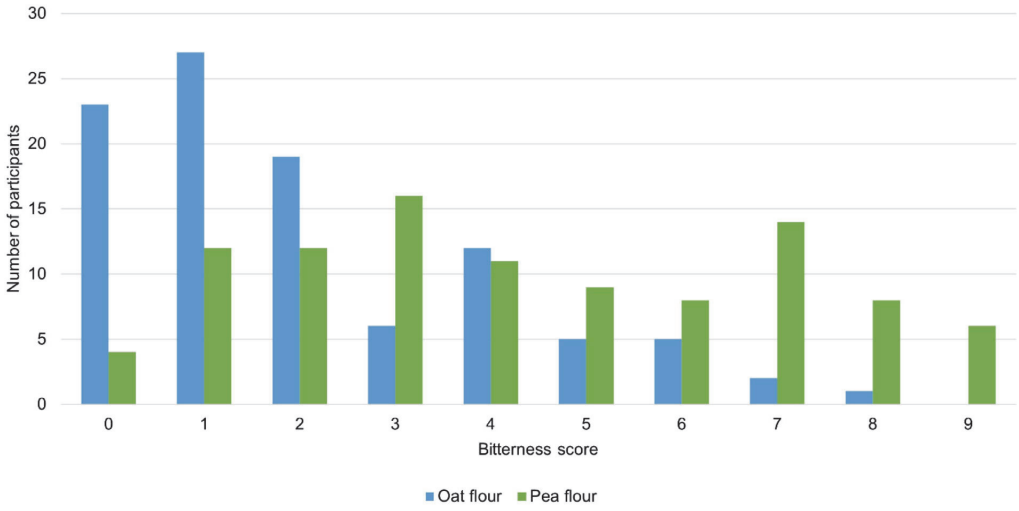

Fig. 4. Distribution of bitterness intensity ratings for pea and oat flour.

related to the bitter perception of oat. However, pea flour's bitterness showed a moderately negative correlation with the fatty acids' bitterness. This is also explained by the fact that the fat content in pea flour was considerably lower than in oat flour (Supplementary Table A.1).

3.3. Consumer test

Fig. 4 Distribution of bitterness intensity ratings for pea and oat flourshows the distribution of intensity ratings among pea and oat flour. The distribution of intensity scores for pea flour were rather uniform across the scale. For oat flour, however, a different distribution can be seen. Most participants perceived no or very low bitterness in oat flour, while only a few people rated the bitterness of oats as high intensity. Thus, oat flour was generally perceived as less bitter (average score 2.1 ± 2.0) than pea flour (average score 4.4 ± 2.6). A similar tendency was seen with trained assessors, who generally scored oat flour's bitterness (average score 3.3 ± 2.6) lower than for pea flour (average score 5.4 ± 2.0).

The distribution of oat and pea bitterness perceived by consumers is shown in Figure A.1 in Supplementary Material. Consumers were grouped into omnivores/flexitarians and vegans/vegetarians based on their dietary habits. Personal scores on the scale were categorized into three additional groups based on the level of bitterness: 0–2 as low, 3–6 as medium, and 7–9 as high. For oat samples, the distribution of the scores did not differ much based on dietary habits. There were only a few people in the omnivore/flexitarian group who were more sensitive to oat bitterness. For pea flour, however, omnivores/flexitarians had a higher proportion of participants highly sensitive to bitterness compared to vegans/vegetarians. Although more vegans/vegetarians were sensitive to the bitterness of pea flour compared to oats, most vegans/vegetarians had medium or low sensitivity to pea flour bitterness.

Wilcoxon rank sum test showed no significant difference in the average bitterness values for different diets. However, there was a significant difference between the bitterness score for pea and oat flours ($p < 0.001$). Further, people were divided into groups based on given ratings for bitterness intensities (0–2 as low, 3–6 as medium, 7–9 as high) as described in chapter 2.5. Pearson's Chi-squared test confirmed that there was no significant difference in bitterness groups for oat flour based on diet patterns. In the case of pea flour, there was a significant difference between bitterness groups ($p < 0.1$). Figure A.1 in Supplementary Material demonstrates that, overall, there were proportionally more omnivores/flexitarians who belonged to the "high" bitterness group compared to vegetarians/flexitarians. Thus, there is an indication of the effect of diet on the bitterness groups with pea products.

4. Discussion

Romano et al. (2008) discuss that there is always some scale variation, although trained panels generally have smaller variations. The present study shows that even when panelists are trained to respond similarly, there is always a possibility for differences due to specific stimulus. There may be bitter molecules that some assessors do not recognize at any level, thus they are not able to rate them on the given scale. It is important to understand whether the difference arose from inadequate training or physiological differences.

Differences in bitterness sensitivity are often investigated using PROP as a bitter standard. For example, Dinehart et al. (2006) showed in their study that the bitterness of vegetables is correlated to PROP sensitivity, whereas bitterness and sweetness of vegetables are associated together with quinine sensitivity. However, since the taste test was conducted with asparagus, brussels sprouts, and kale, these findings do not necessarily explain bitterness perception in other vegetables. Similarly, another study by Duffy et al. (2020) indicated that PROP status is associated with the bitterness of the same vegetables. As previously discussed, plant-based materials can contain various bitter compounds, as well as there are several bitter receptors for different compounds. Therefore, it is difficult to claim that one selected bitter compound can explain the bitterness of all other compounds. Since the TAS2R38 receptor is activated through PROP, research is often focused on this phenotypic variation (Nolden et al., 2020; Tepper, 2008). However, as Hayes & Keast (2011) discuss, the taster status and PROP perception are so intertwined in the scientific literature that it is difficult to change. Although the current study was also focused on plant-based products, no clear connection was shown between PROP taster status and compound sensitivities. Drewnowski and his colleagues (2007) investigated preference for 171 different food items and found that there was no significant relationship between food preference and PROP taster status. It has previously been suggested that the bitterness of different compounds can only be compared if they activate common bitter receptors (Roura et al., 2015). In our study, PROP sensitivity did not correlate with sensitivity to other stimuli either.

Different bitter stimuli varied in stability across sessions. The bitterness of fatty acids and oat flour was having the most variation across

assessors as well as sessions. Firstly, this may be because few assessors were sensitive to these stimuli and perceived them with high intensity. Secondly, the bitterness coming from fatty acids was also described as hot and irritating (Delompré et al., 2019), which may be confusing when interpreted on a bitterness scale. It could also mean that the assessors who evaluated bitterness high for these stimuli, were generally more sensitive to slightly different sensory properties of fatty acids. It must also be noted that the variation in taste threshold values of fatty acids is related to differences in the lipolytic activity of saliva (Delompré et al., 2019). A high salivary lipolytic activity generates high levels of free fatty acids in saliva, which can induce a high taste threshold for free fatty acids due to an adaptation of the taste receptors to basal salivary concentration in fatty acids (Neyraud et al., 2017). Thus, due to a correlation between fatty acid and oat bitterness, people with high sensitivity to oat flour bitterness may have been with high salivary lipolytic activity. However, the correlation between oat flour and fatty acids was expected, as earlier research has shown linolenic acid and linoleic acid to be key bitter compounds in oat (Günther-Jordanland et al., 2020). Pea flour bitterness was not correlated with fatty acids, even though α-linolenic acid and linoleic acid have been considered key bitter compounds among lipids in pea-protein isolates (Gläser et al. 2021). Although the fat content in pea flour was lower than in oat flour, the bitterness of pea flour was generally perceived as more intense. That could mean that saponins or other compounds are more influential on the bitterness of pea flour. Unfortunately, it was not possible to confirm it as the necessary standards were not available in this study.

There are some overlapping receptors (TAS2R7, TAS2R10, TAS2R14, TAS2R43, TAS2R46) for caffeine and quinine bitterness (Meyerhof et al., 2010), but the present study showed a weak negative correlation between sensitivity to these stimuli. Possibly this tendency can be related to the coffee consumption habits of the assessors. In their study, Lipchock et al. (2017) showed that the bitter taste of caffeine was influenced by coffee consumption habits, while quinine consumption is generally less frequent and played a smaller role in quinine sensitivity. It is also possible that all the mechanisms of the bitterness receptors are not yet known. For example, Meyerhof et al. (2010) identified 9 receptors for quinine bitterness, but later publications additionally indicated the existence of TAS2R31 and possibly TAS2R19 (Hayes et al., 2015). Reportedly, L-tryptophan can only bind to the TAS2R4 receptor, which can also be activated by quinine (Kohl et al., 2013). This supports the finding in the current study that L-tryptophan and quinine showed a weak positive correlation in bitterness intensity. There was also a strong positive correlation in the perception of bitterness for both fatty acids. HTC-8 cells have been shown to express both the bitter receptors TAS2R16 and TAS2R38 and the fat taste receptors CD36 and GPR120 (Brissard, 2018). Receptors CD36 and GPR120 are involved in fat taste perception (Ozdener et al., 2014), suggesting that fat and bitter taste share a common signaling mechanism. This implies that similar receptors may have been activated for both linoleic and linolenic acid, showing a strong positive correlation in the perception of bitterness.

Pea flour was generally perceived as significantly more bitter than oat flour. This trend was observed by both consumers and the trained sensory panel. There was no significant difference in the bitterness of oat flour based on dietary habits. However, the proportion of omnivorous/flexitarian consumers who perceived pea products as highly bitter (scores 7–9) was significantly higher than the proportion of vegetarian/flexitarian consumers. Furthermore, this indicates that the bitterness of pea protein products might be more of a limiting factor influencing the acceptance of plant-based products.

The findings reveal the importance of accounting for individual differences in bitter perception when selecting, training, and using sensory panels for different types of plant-based products. The same panel that is sensitive to bitterness in pea-based products may not always be a suitable panel for oat-based products. On one hand, the bitter compounds in the raw materials are generally different, but on the other hand, the concentration of the same bitter compounds is also different. As producers hope to bring well-received alternative products to the market, the use of accurate sensory methods is crucial to optimize production processes.

4.1. Limitations and future research

Due to the unavailability of food-grade saponin standards, major oat and pea saponins were not included in the study. The correlation between saponin bitterness compared to bitterness in oat and pea flour would provide information on the effect of saponins on overall bitterness. Especially, since fatty acids did not correlate with the bitterness of pea flour. As it is not known exactly how saponins affect the bitter taste at the receptor level (Shuntang, 2018), further studies should investigate this issue. The same suggestion applies to lipid compounds, only some of which were included in this study due to limited availability. In addition, previous research mentions other lipid compounds playing an important role in oat and pea bitterness. For example, monoglycerides in oat (Günther-Jordanland et al., 2020) and trihydroxyoctadecenoic acids in peas (Gläser et al. 2021).

There were some samples included in the study that were not fully soluble, specifically precipitating flours and hydrophobic fatty acids. Neyraud (2014) emphasizes that physical properties, such as solubility, can play a role in the perception of bitterness. The author explained that taste compounds must be dissolved in saliva to bind to the taste receptor. However, this does not seem to be an issue for fatty acids since Von Ebner gland protein (LCN1) found in salivary glands can transport hydrophobic fatty acids to taste receptors (Neyraud, 2014). Thus, only in the case of oat and pea flour, solubility could have influenced the perception of bitterness. However, this effect was minimized by selecting appropriate concentrations in preliminary tests and by encouraging stirring of the samples before tasting to ensure homogeneity of samples.

A sensory panel size could also be a limiting factor in this study. A sample size of 12 assessors may not be enough to draw strong conclusions regarding the correlations between PROP and other compounds. Thus, future research could use larger panels in similar studies. However, to address this shortcoming, a consumer test was carried out as a complementary experiment to test the findings of the sensory panel and to provide a larger scale.

This study involved a total of two flours, one from pea and one from oat. As there are many varieties of peas and oats, a more diverse sample could be explored to validate the results of this study. In addition to oat and pea, other raw materials could be investigated in the future. Oats and peas were included in the present study for environmental and nutritional considerations, as well as because the key bitter compounds have been studied previously. However, less is known about other potential raw materials, such as various legumes (e.g. fava beans, chickpeas, lupins), which are often used in plant-based alternatives, but their use is limited due to bitterness. Therefore, there is room for further research on bitterness in the context of plant-based alternatives.

Food liking and acceptability are not only related to bitterness but also other product characteristics. For example, odor profile has an important effect on food acceptability of plant-based alternatives. Duffy et al. (2020) demonstrated that a more intense flavor enhances the intensity of bitterness of the green vegetables tested. However, this was not the focus of this research as nose clips were used in this study. For example, cis-3-hexen-1-ol is found in various plant-based products (Caporale et al., 2004; Vaikma et al., 2021), but also can affect food preferences due to an individual's ability to detect this compound (Hayes et al., 2013). In the future, the interaction of bitterness with other product characteristics on the pleasantness of food (incl. plant-based alternatives) can be explored.

5. Conclusions

Bitterness is a complex mechanism, thus variation in bitterness perception should be considered when putting together a sensory panel and

conducting sensory tests for plant-based products. This is also demonstrated by the tendency that PROP sensitivity was not a general indicator of higher sensitivity to other bitter stimuli. Although the PROP test is often used to measure individual differences in bitterness perception, these results show that this is not always justified. Furthermore, it is debatable whether it is possible to use a general reference to bitterness, as is often done (e.g. quinine, caffeine). In the present study, it was not possible to standardize the sensory data using quinine because assessment scores for different stimuli were not in correlation with quinine scores. Variations in sensitivity varied depending on the bitter stimulus. Therefore, it seems that a more precise standard is needed for the assessment of the products made from a specific raw material. The need for different standards may already arise when comparing raw materials.

When comparing pea and oat samples, most people were sensitive to the bitterness of the pea samples. This trend was confirmed by both the sensory panel and the consumer test. There were also significantly more omnivores/flexitarians who perceived pea bitterness on a higher level than vegans/vegetarians. Fewer people perceived oat bitterness more intensely, but this was found to correlate with sensitivity to fatty acid bitterness. This implies that a high sensitivity to oat bitterness is related to individual sensitivity to fatty acids. In conclusion, developers of plant-based alternatives should take the individual differences of the general population into consideration.

Ethical statement

All participants from the sensory panel as well as the consumer panel gave written consent to take part in the experiment. Participants were informed in advance of the purpose and the procedures of the study. Participants were assured of the confidentiality of their data. Taking part in the given study was voluntary and one could withdraw from the test at any time. Participants were in good health and had no known allergy to the components. The ethical statement in the given manuscript is also included in chapter 2.1.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

CRediT authorship contribution statement

Helen Vaikma: Conceptualization, Methodology, Investigation, Data curation, Formal analysis, Writing – original draft. **Grete Metsoja:** Conceptualization, Methodology, Investigation, Data curation, Formal analysis, Visualization, Validation, Writing – original draft. **Anastassia Bljahhina:** Writing – review & editing. **Sirli Rosenvald:** Conceptualization, Supervision, Methodology, Writing – review & editing.

Data Availability

Data will be made available on request.

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Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.fufo.2022.100206.

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Appendix 3

Article III
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Unveiling the mindset: measuring consumer perception towards the dimensions of sustainability

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Scale development

ABSTRACT

Sustainability tackles challenges such as environmental balance, social equity, economic stability, and health. As a theoretical implication, this study introduces a multidimensional framework for understanding how consumers perceive sustainability. The prevalent model of sustainability encompasses three dimensions: environmental, economic, and social. This study distinguishes health as a separate dimension from the social, underscoring its significance in consumer goods preferences. Since consumers also perceive and interpret sustainability's dimensions in diverse ways, understanding these perceptions is key to developing effective sustainability strategies. Study 1 ($N = 1019$) employed Exploratory and Confirmatory Factor Analysis (EFA, CFA) to develop and validate a four-dimensional scale (social, economic, environmental, health) across four European countries. Study 2 ($N = 926$) validated a shorter CFA version and examined demographic differences in Sweden and Italy, selected by their contrasting sustainability values in EU reports. The Sustainability Dimensions Perception Scale (SDPS) revealed five consumer clusters: Sustainably Conscious (28 %), Sustainability Sceptics (7 %), Green Health Advocates (27 %), Moderate Supporters (22 %), Health Neutralists (16 %). These clusters varied demographically: older individuals aligned more with health statements, plant-based food consumers resonated more with social and environmental statements, women agreed more with social statements, and Italians rated all dimensions higher. These findings emphasise the need to educate specific consumer groups about less prioritised dimensions or improve related policies. Meanwhile, focusing on the more valued dimensions can guide product development and refine marketing strategies.

1. Introduction

Sustainable behaviours are crucial for establishing an equitable, secure, and healthy environment for both nature and its inhabitants. The United Nations (UN) has specified its primary objectives for the forthcoming years through the Sustainable Development Goals (SDGs) [1]. Extant research has focused on these goals and on individual sustainable perceptions and behaviours [2,3]. Among various conceptualisations of sustainability, one of the most well-known and widely utilised [4–6] frameworks is the tripartite construct outlined in the UN's Agenda 21 [7], which includes environmental, economic, and social dimensions.

Despite growing attention to sustainability, several gaps persist in the literature. First, much research focuses on one or two dimensions of sustainability [8], with a particular emphasis on the environmental dimension [9,10]. Scholars have repeatedly highlighted the need to transition from this unidimensional focus to a more comprehensive approach, which would enhance the understanding of factors influencing consumer perceptions of sustainable decisions and to develop efficacious strategies [8,10].

Second, while many studies explore how attitudinal factors affect consumer behaviour [8,10], the underlying motivations often remain unexplored due to their complexity, and studies sometimes yield contradictory findings [9,11]. This complexity arises because perceptions are influenced by various socio-demographic factors and specific product categories [12,13]. Previous studies have demonstrated that sustainability can mean different things to different people [12–17] and it is often difficult to define sustainability. For example, it could be perceived that social dimension is more short-term and local, and the environmental dimension is more long-term and global [14]. This highlights another gap in research regarding how people's perceptions of sustainability differ based on their interpretations of its various dimensions [8,10,14,16].

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Third, understanding sustainability perceptions is essential to uncovering the factors that lead to behaviours [18]. While sustainability metrics is a popular topic, it primarily focuses on measuring the impacts of behaviours [19]. On one hand, consumer behaviour plays an important role in shaping (and even predicting) sustainability practices, as often examined how market dynamics and consumption trends interact [20]. On the other hand, focusing primarily on behaviour leaves gaps in understanding the underlying perceptions that shape these actions. Addressing these gaps can help identify potential discrepancies between attitudes and actions [21,22].

The objective of this study is to develop a multidimensional measurement tool for consumer perceptions of sustainability, encompassing social, economic, environmental, and health dimensions. This tool aims to account for both overall and demographic variations to better understand perceptual differences, which is essential for gaining insights into consumers' perspectives and encouraging them to adopt sustainable attitudes. Offering insights into the complexities of sustainability perceptions can inform educational, policy, and marketing strategies [11,13,18] and raise awareness of sustainability's nuanced dimensions. Additionally, by revealing the important sustainability dimensions, it can offer producers to find ways to encourage consumers toward more sustainable choices [23,24]. The ability to compare perceptions across these four dimensions provides novelty in the field.

Similar to sustainability research, existing perceptual sustainability scales often emphasise the environmental dimension (Table 1), which limits their ability to capture the full complexity of consumer perceptions. Although multidimensional perceptual scales have recently emerged (i.e., ASD, SCQ in Table 1), they primarily rely on the abovementioned UN's three dimensions, potentially overlooking certain themes, such as the health aspect [25]. Rather than of using a top-down approach based on UN subthemes, this study adopts a bottom-up approach to capture diverse perspectives that reflect the complexities of consumer perceptions, which might otherwise be overlooked or overgeneralised. This approach provides deeper, multidimensional understanding of sustainability perspectives, offering valuable insights for stakeholders aiming to guide consumer behaviour toward more sustainable decisions. Moreover, while many existing sustainability scales are tailored to specific domains, such as educational settings [26] (see also Table 1), consumer perceptions often vary significantly across different contexts [12]. Therefore, this study's approach aims to capture a broader range of sustainability aspects rather than focusing on a single category [9]. This flexibility makes the scale adaptable and relevant for stakeholders in multiple contexts. Further, since various psychological, marketing and sensory factors can influence consumer decisions [20], this study provides a robust framework for understanding sustainability-related decision. It achieves this by enabling the measurement of perceptions of sustainability dimensions and facilitating comparisons with other influencing factors in future research.

The publication follows four stages, adapted from the full procedure by MacKenzie et al. [41]. These stages are: (I) measurement building, where the initial constructs were formulated to develop the conceptual framework, (II) model testing and validation, where the preliminary version of the scale was tested with consumer data to refine it, (III) further validation, where the refined version of the scale is tested on a new set of consumer data; and (IV) implementation through practical application, where the measurement tool was applied in real-world settings to assess its practicality and relevance to existing literature. Each stage contributes to developing a robust, multidimensional

Table 1
Previous scales developed in sustainability perception studies, referenced [27–40].

Scale [reference]	Year	Conceptual design	Use	Limitations
Ecology Scale [27,28]	1973; 1975	Developed from ~500 diverse response items, refined by independent judges, and shortened in a later publication.	Assesses commitment, affect, and knowledge on ecological issues.	Outdated topics [31], lacks comprehensive quality evidence [32], limited to the environmental dimension
New Environmental Paradigm Scale (NEP Scale); [29,30]	1978; 2000	Based on NEP-oriented literature; later refined with updated terminology and a broader range of ecological factors.	Measures NEP acceptance among the general public, recognised by UNESCO.	Outdated language, overly simplistic [29], ecocentric rather than anthropocentric [31], limited to the environmental dimension
Environmental Concern Scale [32]	1978	Derived from 31 items related to conservation and pollution, collected from 141 randomly selected participants in a prior study	Measures attitudes toward individual beliefs and feelings about ecology.	Outdated topics [31], limited to the environmental dimension
Children's Environmental Attitude and Knowledge Scale (CHEAKS) [33]	1995	Based on the original 45 items from the revised Ecology Scale [28]	Assesses attitudes and ecological knowledge, the first measure designed for children.	Developed for the environmental education context, limited to the environmental dimension
Attitude and Behaviour Scale for Environmental Perspectives of Pupils [34]	1996	Grounded in attitude theories, such as the Tripartite Model of Attitude.	Measures environmental concern and behaviour among students.	Developed for measuring adolescents (students), limited to the environmental dimension
Environmental Attitude and Ecological Behaviour [35]	1999	Based on the Theory of Planned Behaviour	Measures environmental knowledge, values, and behavioural intentions.	Limited to the environmental dimension.
Two Major Environmental Values (2-MEV) scale [36]	1999	Built upon a previous scale by Bogner and Wilhelm (1996) [34]	Measures perceptions of environmental "Utilization" and "Preservation".	Developed for measuring adolescents, limited to the environmental dimension
Environmental Attitudes Inventory (EAI) Scale [31]	2010	Based on prior scales measuring environmental attitudes from various perspectives	Includes 12 scales capturing key aspects from previous studies.	Limited to the environmental dimension.
Knowledge, Attitudes and Behaviours Concerning Education for Sustainable Development [37]	2011	Rooted in the UN's framework for education for sustainable development (UNDESD)	Measures knowledge, attitudes and behaviours in education for sustainable development and/or sustainable development (ESD/SD)	Focuses on ESD/SD only, general perception of sustainability lacks dimensionality.
Attitudes towards Sustainable Development scale (ASD) [38]	2017	Drawn from the UN's sustainability framework and ESD learning methods.	Measures sustainability attitudes across multiple dimensions (environment, economy, society, education)	Designed for education rather than general use. Limited to UN dimensional constructs, thus may overlook certain themes.
Sustainability Consciousness Questionnaire (SCQ) [39]	2019	Aligned with the UN's sustainability subthemes and constructs from a previous scale by Michalos et al. (2011) [37]	Measures knowledge, attitudes, and behaviours in sustainability across multiple dimensions.	Limited to UN constructs, may overlook certain themes, and thus be restricting in specific settings.
Self-Perceived Action Competence for Sustainability (SPACS-Q) [40]	2020	Based on a Reasonable Person Model	Measures action competence; no psychometric instruments exist for this concept.	General perception of sustainability, lacks dimensionality and may be limited in specific contexts.

Sustainability Dimensions Perception Scale (SDPS), ensuring its validity and applicability across diverse contexts.

2. Conceptual framework

Various conceptualisations of sustainability depend on the context. The common three-dimensional model of sustainability, established in 1992 by the UN through Agenda 21 [7], is not the sole framework for understanding sustainability. Some studies, for example, have incorporated additional dimensions such as health [5], while others have proposed entirely new concepts. An instance of this is the integration of personal, permanence, and three-dimensional space into a sustainability model for policymaking [42]. In the field of cybernetics, research defined sustainability through material, economic, life, social, and spiritual domains [43]. These examples highlight that concepts of sustainability can vary significantly depending on the field and objectives. While this study primarily follows the conventional three-dimensional model, it includes health as a separate dimension due to its importance in the context of consumer goods, such as organic foods [13], organic cosmetics [44], furniture [45], fashion [46] and electronics [47]. Therefore, this study approaches sustainability as a four-dimensional construct that combines social, environmental, economic, and health dimensions.

Generally, promoting sustainability aims to address different global issues while strengthening universal peace [1]. Developing the measurement required first identifying constructs that define each dimension and distinguish them from others [41]. Based on the chosen four-dimensional structure, the corresponding issues were defined as follows [1,48]:

- **Social** issues refer to inadequate living conditions, inaccessibility to natural resources or urban spaces, poor workers' rights, social inequity (e.g., by gender, sex, race), low-quality education, lack of stakeholder involvement, lack of freedom of speech.
- **Environmental** issues include climate change, depletion of resources (i.e., food, energy), greenhouse gas emissions, soil erosion, pollution and waste generation, loss of biodiversity.
- **Economic** instability refers mainly to economic and financial crises and issues, including poor supply chain management, inefficient production (including cost and quality), poor resource distribution.
- **Health** issues refer to pandemics and communicable diseases (e.g., influenza, tuberculosis, hepatitis, HIV), non-communicable diseases (e.g., cancer, cardiovascular diseases), lack of safe food/water, and a general decline in happiness.

Sustainability dimensions are often deeply interconnected [49]. For instance, environmental sustainability issues like climate change can negatively impact health and increase social and economic inequalities [50,51]. Some interconnections may also mislead [49]; for example, while fair trade products aim to promote social and economic equality, consumers often associate them with environmental [52] or health [53] benefits. However, not all interactions among these dimensions are complementary. Economic growth driven by the exploitation of natural resources, such as oil and coal, increases environmental degradation [54]. Previous research has also indicated that the prioritisation and perception of these dimensions can depend on the context [55]. Therefore, it is crucial to view sustainability as an interconnected system, recognizing that strategies aimed at improving one dimension can have both positive and negative effects on the other dimensions.

3. Methods

This study follows a four-step construct measurement and validation process (Fig. 1) adapted from MacKenzie et al. [41]: (I) measurement building (combining Steps 1–4), (II) model testing and validation with the preliminary version (Steps 5–6), (III) further validation with the refined version (Steps 7–9), and (IV) implementation through practical application. Stage I involved the conceptualisation and development of measures based on previous literature and discussions with experts, resulting in a 61-item scale concept. In Stage II, I tested and validated the initial scale through Study 1, followed by scale refinement based on the obtained results. Stage III involved conducting additional testing, including validity and cross-validity assessments, on the refined 22-item scale in Study 2. In Stage IV, I entailed the application of the scale through cluster analysis and a discussion of its implementation. Additionally, I analysed demographic variables to assess the scale's reliability. All four stages contributed to the study's objective of developing a tool to examine how various consumers perceive sustainability across its multidimensional aspects.

3.1. Data collection

Project team completed the data collection between April and June 2022 (Study 1) and October 2022 (Study 2). The fieldwork was conducted by TFTAK (Tallinn, Estonia) and SAM Sensory and Consumer Research (Munich, Germany). Participants spent approximately 16 min on average in Study 1, and approximately 5 min in Study 2. Researchers informed participants of the purpose and procedures of the study, and were told they could withdraw from the test at any time. The data collection and analysis were conducted confidentially, ensuring data privacy for the participants.

The team collected data from Study 1 in four different countries: Sweden, Italy, Estonia, and France. They distributed the surveys online in each national language. Countries were selected to represent sustainably contrasting regions that were also geographically dispersed, covering Northern, Southern, Eastern, and Western Europe. Previous

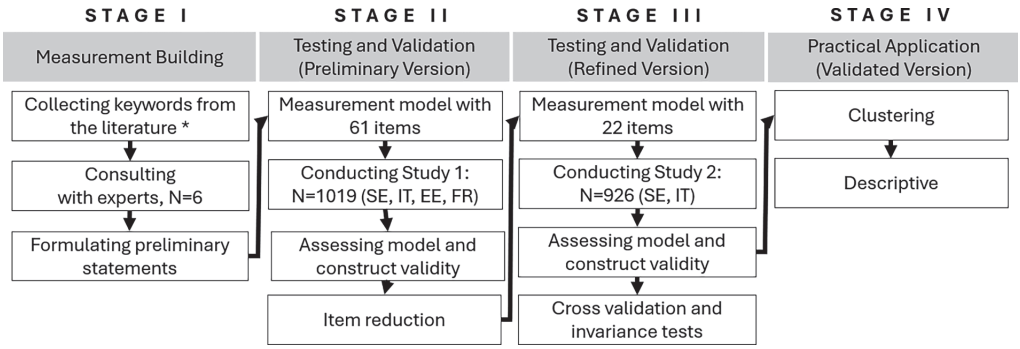

Fig. 1. Flow diagram of the study, from concept building to practical application. *References found in Appendix A1.

data from Eurobarometer reports suggested that Swedes and French considered environmental protection [56] and "social Europe" [57] more important compared to the EU average, whereas Estonians and Italians viewed these as of low importance compared to the EU average. Further, Swedes considered environmental protection the most important among other EU countries, whereas Italians considered social protection the least important. The assessment of each country's SDGs [58] showed a similar tendency. Thus, the team conducted Study 2 in Italy and Sweden, assuming that these countries provide the most contrast.

A general guideline suggests that research needs 5 to 10 subjects for each variable being tested [59]. Therefore, to estimate an appropriate model for this study using Exploratory Factor Analysis (EFA), the study requires at least 610 participants (preliminary SDPS of 61 items). To validate the model through Confirmatory Factor Analysis (CFA), the author estimated the necessary sample size to achieve sufficient statistical power using GPower software version 3.1.9.7 [60]. With an α error probability at 0.001 and the power (1 – β) at 0.99, the total required sample size is at least 626. Based on similar studies focusing on scale development [61,62] and factor analysis recommendations [63], a minimum of 1000 participants were included across both studies, irrespective of the number of variables. However, I excluded some responses from the analysis due to excessively incomplete answers [64] or straight-lining behaviour [65]. In conclusion, 1019 respondents were included in Study 1 and 926 were involved in Study 2. As a result, this study possesses more than adequate statistical power for its intended purposes.

Incentives (gift cards) were used to motivate participants to remain active until the end of the scale. In each country, data were obtained using quota sampling in terms of gender and age. This was because of the finding that the understanding of sustainability can be related to demographic factors [12,13,66,67]. The samples were representative of the country's population by median age [68], with the medians falling within the 35–54 year age group in both studies. Quotas were designed to ensure approximately equal representation of all subgroups, fostering comparability both across countries and within various demographic segments. This enhances comparability among underrepresented groups while ensuring sufficient statistical power to analyse various groups [69]. Participants were split 50–50 by gender, while age was split by 1/3 per age group (18–34, 35–54, and 55+). Underage respondents were excluded from the study due to the complexity of the topic.

Information on participants' dietary habits was also obtained, as various sustainability issues (environment, health, and welfare) can play an important role in people's dietary habits [17,70]. Building on previous research [71], respondents were asked to select the statement that best represented their dietary habits. For data analysis, participants were categorised into two groups: omnivores and diet-conscious (i.e. flexitarians, vegetarians, and vegans). Categorising them into a single group has been observed in prior studies [72,73], and is justified as diet-consciousness is closely associated with veganism, vegetarianism, and flexitarianism [74,75].

3.2. Data analysis

Exploratory Factor Analysis (EFA) was performed to evaluate the scale structure. To reduce potential bias in later analyses, I estimated missing data ("I don't know" responses) using the Expectation-Maximization method or excluded subjects with more than 20 % [64] missing responses. As the next step, I split the data and assessed its suitability for analysis through preliminary tests in R version (R Foundation for Statistical Computing, Vienna, Austria). These included the Kaiser-Meyer-Olkin (KMO) measure of sampling adequacy (R package "psych") and Bartlett's test of sphericity (R package "stats"). I conducted subsequent analyses in IBM SPSS Statistics version 28 (International Business Machines Corporation, New York, USA). During EFA, I selected factors based on the Kaiser criterion, retaining those with Eigenvalues greater than one, and excluded items with low factor loadings (<0.40) and/or cross-loadings. Reliability was assessed based on internal consistency using Cronbach's α.

Confirmatory Factor Analysis (CFA) was conducted using IBM SPSS Amos version 28 (International Business Machines Corporation, New York, USA). I assessed the goodness-of-fit of the model based on five different fit measures: chi-square statistics (χ^2), root mean square error of approximation (RMSEA), goodness-of-fit index (GFI) for absolute fit, comparative fit index (CFI), Tucker-Lewis index (TLI) for relative fit, and parsimonious CFI (PCFI) and adjusted GFI (AGFI) for parsimonious fit [76]. Researchers generally accept that the χ^2/df ratio should not exceed 5 (*df* represents the degrees of freedom) [77]. For other fit indicators, they consider cut-off values of ≤0.08 for RMSEA [78], ≥0.80 [79] for CFI and TLI, >0.80 [78] for GFI and AGFI, and ≥0.5 for PCFI [76].

I tested construct validity by focusing on convergent and discriminant validity. Convergent validity was confirmed when similar measured constructs showed a correlation in the results, whereas discriminant validity was established when the correlation between different measured constructs was low [80]. Based on the Fornell-Larcker criterion, convergent validity is provided when the Average Variance Extracted (AVE) is greater than 0.50 and discriminant validity exists if the square root of AVE for the given construct were greater than the correlations with other constructs [81]. However, I considered AVE from 0.40 acceptable when the composite reliability exceeded 0.60 [81]. Additionally, I confirmed convergent validity if the standardised factor loadings were greater than 0.50, and composite reliability (CR) was not less than 0.70 [80]. Discriminant validity was also confirmed by the heterotrait-monotrait (HTMT) ratio, with a threshold value of 0.85 and or below [82]. I further validated the final version of the scale through cross-validation and invariance tests.

For additional exploratory analyses, I conducted descriptive statistics and significance testing in R version 4.1.1 (R Foundation for Statistical Computing, Vienna, Austria). Given that Shapiro-Wilk tests indicated non-normality in the data, I assessed statistical significance using non-parametric tests: the Kruskal-Wallis test and the Mann-Whitney U test (all performed using R package "stats"). Furthermore, I applied K-means clustering to categorise the data. This method is widely used for its efficiency, flexibility, and straightforward implementation [83]. The number of clusters was identified using the elbow method and then clustered by the K-means algorithm (R package "factoextra"). Each variable in the dataset represented a specific statement from the scale. To visualise how different sustainability dimensions were correlated with various clusters, I projected the data into a lower-dimensional space [84]. Principal component analysis (R package "prcomp") was used to determine the direction and explained variance of the variables.

4. Results and discussion

4.1. Measurement building (Stage I)

Building on insights from previous literature and the conceptual framework mentioned earlier, I began the scale development process by collecting keywords from published papers and documents focusing on the perception of sustainability and sustainable behaviour. Each keyword was categorised into a specific sustainability dimension and keywords were used as the basis for formulating the statements. To assess the content validity of each item [41], I consulted academic and industry experts (*Acknowledgements*). They provided feedback on whether a) the statements were unambiguous or needed reformulation, b) any relevant topics were missing from the initial list, and c) the scale used was appropriate for this study. Based on their feedback, I included 11 additional statements.

A 7-point Likert scale was chosen to assess participants' opinions, ranging from "strongly disagree" (1) to "strongly agree" (7). The focus was not on how much consumers know about these different global issues but rather how they perceive different sustainable activities. To allow for more accurate responses, I included an "I don't know" option,

so participants were not forced to select from the scale. To minimise order bias, I randomised the order of question blocks (dimensions) and statements within the groups across participants. The need for reversed items was also considered but ultimately excluded, as positive and reversed items could have different meanings depending on linguistic skills [85].

Finally, I categorised all formulated statements into specific dimensions based on the multidimensional model outlined in the conceptual framework, establishing a formal measurement model for subsequent testing [41]. This resulted in a 61-item scale, with 16 items for the environmental dimension and 15 items for each of the social, economic, and health dimensions. Appendix A1 presents the complete set of statements within each dimension along with their origins.

4.2. Testing and validating the preliminary model (Stage II)

The research team gathered data for Study 1 to test the formal preliminary model and refine the scale using factor analysis [41], aiming to create a shorter, more convenient, and time-efficient tool. I began the data analysis by randomly splitting the complete data in half, with the first subset of exploratory results being confirmatively tested on the second subset [86]. Exploratory Factor Analysis (EFA) was conducted on a subsample, subset A ($N = 509$) from Study 1, and confirmed that the sample was suitable for further analysis, based on the Kaiser-Meyer-Olkin test showing sampling adequacy with a value of 0.93, and Bartlett's test of sphericity showing statistical significance (<0.001). I extracted final items using principal component analysis with oblique rotation, which resulted in 25 items in total. Elements were projected into four factors, with each factor containing at least five elements. Eigenvalues for the four factors ranged from 9.18 to 1.19, collectively accounting for 55.17 % of the variation. Cronbach's α for the overall EFA model was 0.92, indicating good reliability. I titled the factors identified in EFA as follows: Factor 1 as "Social dimension", Factor 2 as "Health dimension", Factor 3 as "Economic dimension", and Factor 4 as "Environmental dimension".

The EFA model was tested using Confirmatory Factor Analysis (CFA). When I assessed subset B ($N = 510$), the model showed an acceptable fit (χ^2/df =3.56, RMSEA 0.07, GFI=0.86, CFI=0.91, TLI=0.92, PCFI=0.81, AGFI=0.83). However, I removed three items from the CFA model due to their lower standardised regression weights (<0.60). These steps improved model fit with most criteria (χ^2/df =3.22, RMSEA 0.07, GFI=0.99, CFI=0.93, TLI=0.92, PCFI=0.81, AGFI=0.87). I also tested the model with each country's dataset in Study 1 and confirmed a good fit (Appendix A2). The final model resulted in 22 items: 7 items for "Social dimension" (Cronbach's α=0.90), 5 for "Health dimension" (α=0.85), 5 for "Economic dimension" (α=0.81), 5 for "Environmental dimension" (α=0.83).

To ensure the model's quality, I confirmed the convergent and discriminant validity through various analyses (Appendix A3). The factor loadings ranged from 0.63 to 0.82, all exceeding the cut-off value. Each construct met the composite reliability criterion (>0.60), and AVE values were close to 0.5, confirming the model's convergent validity. Additionally, the square root of AVE was greater than the correlations between constructs (Fornell-Larcker criterion), and the HTMT did not exceed 0.85, demonstrating clear signs of discriminant validity.

The results confirm the preliminary model's validity, clearly establishing the four dimensions identified in Stage I ("Measurement building"). Separating the health dimension from the original UN's three sustainability dimensions [7] proves to be appropriate, as factor analysis shows these dimensions are distinct. This expansion provides a holistic approach to sustainability, enabling a comprehensive understanding of the factors influencing consumer perceptions of sustainability [8,10]. While the use of the original UN dimensions is consistent with prior research [4,6,7,39], the addition of health enhances the framework's applicability in more varied contexts such as consumer goods.

4.3. Further validation of the refined scale (Stage III)

The team gathered new data in Study 2 to reexamine the scale through further validation and cross-validation of the refined version of the SDPS [41]. CFA showed acceptable model fit (χ^2/df =4.23, RMSEA 0.06, GFI=0.92, CFI=0.94, TLI=0.93, PCFI=0.82, AGFI=0.90) for the 22-item SDPS. Hence, I confirmed the revised version of the scale to be suitable for the given model. Further, some goodness-of-fit indicators were improved (smaller RMSEA and larger CFI, TLI, PCFI, AGFI) compared to Study 1. I suggest that the quality of the data was better since the shortened SDPS was less time-consuming, and participants were able to maintain focus during data collection.

Similarly to Study 1, construct validity in Study 2 was confirmed by investigating convergent and discriminant validity. I have provided the specific values in Appendix A3, with the criteria explained in Data Analysis (3.2). The revised scale in Study 2 was further validated through various cross-validation and invariance tests conducted across both countries. Loose cross-validation demonstrated that the model remained valid even when I tested it separately with two sample groups (model fit results are provided in Appendix A4, and factor loadings found in Appendix A5). I again tested the factor structure equivalence in both samples, but this time I evaluated the model simultaneously, in contrast to the loose cross-validation approach. The results indicated a good fit (values shown in Appendix A4), further confirming that the same model structure is valid for both samples. Thus, the sample exhibited configural invariance. Next, I performed various equivalence tests (see also Appendix A4). The full metric invariance test revealed that not all factor loadings were equal ($\Delta\chi2$=48.35, $p < 0.001$), indicating a lack of invariance. However, the partial loading equivalence test, which focused on eight items (the two most similar loadings in each construct), showed that some aspects of the constructs were comparable ($\Delta\chi2$=13.48, ns), confirming partial metric invariance. Finally, I tested interfactor covariance equivalence ($\Delta\chi2$=163.76, $p < 0.001$) and error variance equivalence ($\Delta\chi2$=431.44, $p < 0.001$), both of which showed significant differences. This indicates that the interfactor and error variances are not invariant, although the latter rarely is achieved [87,88].

The revised and validated version of the final scale is presented in Appendix A5. The social dimension (S) included topics such as building a sustainable future (S1, S4), food culture and policies (S3, S5), and safeguarding people (S2, S6, S7). The economic dimension (EC) included items about innovation (EC2, EC3) and finance (EC4). The environmental dimension (EN) included topics such as packaging (EN2, EN5), whereas the health dimension (H) focused on various health benefits (H2). Some topics also recurred in different dimensions, e.g. production processes (EN4, EC1, EC5, H1, H5) and localness/seasonality (EN1, EN3, H3, H4). This suggests that certain topics are relevant to consumers in various dimensions of sustainability, which could also be one of the reasons why the meaning of sustainability can vary greatly among individuals [12–17]. These overlapping themes further indicate that sustainability is a complex, interconnected concept [49], as previously discussed.

Items excluded from the final scale covered topics such as recycling (EN), organic (H), pricing (EC), localness (S), but also some recurring themes like second-hand products (EC, EN) and plant-/animal-based products (EC, EN, H, S). While some of these items showed great variability of opinions, such as topics about plant-based, they did not seem to fit well with the model based on factor analysis. This suggests that certain perceptions are less strongly influenced by sustainability reasoning compared to habitual behaviours. Previous studies have indicated that expressing sustainable behaviour involves thought processes (including attitudes and beliefs) and habits, with some consumers more willing to adapt their habits, such as limiting meat consumption [8,70]. These personal habitual characteristics may explain why these items did not align with the factor model, indicating they may represent a different aspect of consumer perceptions.

4.4. Sustainability dimensions from a consumer perspective (Stage IV)

After validating the refined scale, I further explored the data to uncover consumer perceptions of the sustainability dimensions. I examined consumer perceptions based on the results of Study 2 and presented the socio-demographic characteristics of the participants in Table 2. I used two approaches to analyse the results. First, comparing statements by considering means with standard deviations, significance tests, and differences in agreement (Appendix A5 as an example). Agreement was indicated by a score of 5–7 on a 7-point scale and subtracted for the absolute difference (Appendix A6). The self-reported values for a particular dimension were averaged to determine demographic differences between the dimensions. For instance, averaging all social statements together as the social dimension and all health statements together as the health dimension. Although participants generally agreed with sustainability statements, they showed the highest agreement with the environmental dimension (87.2 % of the total sample), followed closely by the social dimension (86.7 %), the economic dimension (85.1 %), and the health dimension (85.0 %).

Second, I conducted clustering to explore possible variations between consumers in depth. The clustering of dimensions revealed five different groups of consumers (Fig. 2). In Cluster 1 ($N = 257$), I found the highest agreement with all four dimensions, with most participants being Italian (63 %) and fewer being aged 18–34 (27 %). Thus, I labelled this cluster Sustainably Conscious. In Cluster 2 ($N = 61$), I observed consumers with the lowest agreement with different sustainability dimensions on average. They were especially sceptical about social, environmental, and health dimensions. Hence, I named this cluster Sustainability Sceptics. These respondents were more likely to be men (62 %), omnivorous (80 %), from Sweden (70 %), and less likely to be aged 18–34 (28 %). In Cluster 3 ($N = 253$), I mostly saw agreement with different sustainability dimensions, although the participants were a bit more neutral about economic sustainability statements. They seemed to agree with the health and environmental dimensions more, so I labelled them Green Health Advocates. The demographic characteristics of this group were similar to those of Sustainably Conscious. In Cluster 4 ($N = 203$), I noted a rather neutral stance on different sustainability dimensions, with most participants being Swedish (60 %) and omnivores (75 %), but less likely to be in the 55+ age group (26 %), describing this cluster as Moderate Supporters. In Cluster 5 ($N = 152$) was differentiable by the highest proportion of the youngest age group (44 % of 18–34). These consumers agreed less often with the health dimensions, so I labelled them Health Neutralists.

Social dimension appeared to be more important for diet-conscious (incl. vegetarians, vegans, flexitarians) participants compared to the omnivores ($\bar{x}_{\text{Omnivores}}=5.7 \pm 1.3$; $\bar{x}_{\text{Diet-conscious}}=6.2 \pm 1.1$; $p < 0.001$). Research shows that increased consumption of plant-based foods is often driven by moral motivators such as concerns about animal welfare [70]. Furthermore, promoting a plant-based diet is often related to food equality by improving agricultural efficiency [89]. Diet-conscious also stressed the importance of promoting sustainability, as they considered it more important that "knowledge of sustainable consumption must be passed on to future generations" (S1) ($\bar{x}_{\text{Omnivores}}=5.7 \pm 1.2$; $\bar{x}_{\text{Diet-conscious}}=6.2 \pm 1.1$; $p < 0.001$) and that "surrounding food culture must promote a sustainable diet" (S3) ($\bar{x}_{\text{Omnivores}}=5.4 \pm 1.3$; $\bar{x}_{\text{Diet-conscious}}=6.1 \pm 1.0$; $p < 0.001$). Diet-conscious people may be generally more knowledgeable about social sustainability issues, making them more supportive (Appendix A6). Studies have shown that educated consumers are likely to associate environmental sustainability with the social dimension [66].

Diet-conscious people also agreed more often with the statement ($\bar{x}_{\text{Omnivores}}=5.2 \pm 1.3$; $\bar{x}_{\text{Diet-conscious}}=5.8 \pm 1.1$; $p < 0.001$) that fair trade products should be preferred to improve social justice (S2). Studies have shown that vegans and vegetarians tend to consume more fair trade products [90,91]. However, consumers often associate fair trade with environmental concepts [52]. Therefore, the differences among diet groups may stem from different perceptions of fair trade. In particular, there seemed to be a relationship between diet habits and the environmental dimension, with diet-conscious showing higher agreement with environmental themes ($\bar{x}_{\text{Omnivores}}=5.7 \pm 1.3$; $\bar{x}_{\text{Diet-conscious}}=6.1 \pm 1.1$; $p < 0.001$). Sustainability Sceptics, with generally lower perceptions, also seemed to indicate a similar tendency, as it was mainly composed of omnivores. After all, increased interest in plant-based products is often driven by environmental issues [70], especially among younger generations [92]. Thus, social and environmental aspects may be closely intertwined in certain topics.

The lowest agreement with different sustainability dimensions was more likely among men, as indicated by their classification as Sustainability Sceptics. The literature seems to support that women are more sustainably conscious than men; for example, studies show higher social concern for women [93,94]. The present study also seemed to indicate that the social dimension was generally less important for men ($\bar{x}_{\text{Men}}=5.7 \pm 1.3$; $\bar{x}_{\text{Women}}=6.1 \pm 1.2$; $p < 0.001$), with all social statements (except S6) showing a statistical significance. However, it's previously discussed that stereotypes shape how people respond to topics, and thus may also influence gender differences in how sustainability is addressed [95]. If some sustainable behaviours are not seen as masculine, men are less likely to engage. Thus, I must note that gender differences are not always easy to distinguish.

Agreement with the health dimensions appears to become more important as the age range increases, with less agreement among 18–34-year-olds compared to 35–54-year-olds ($\bar{x}_{18–34}=5.5 \pm 1.2$; $\bar{x}_{35–54} = 5.7 \pm 1.2$; $p < 0.01$) and 55+ age groups ($\bar{x}_{55+} =5.8 \pm 1.3$; $p < 0.001$). Health Neutralists, with the highest proportion of the youngest age group, also seem to indicate this. Previous research shows that older consumers tend to pay more attention to health aspects, such as looking more often at nutritional and health claims on food labels [96], and are more likely to choose products with clean labels [97]. I observed a significantly lower agreement among younger respondents regarding the seasonality (H3) and localness (H4) of food. Younger repondents generally agreed less that seasonal ($\bar{x}_{18–34}=5.6 \pm 1.2$; $\bar{x}_{55+} =6.1 \pm 1.0$; $p < 0.001$) and local ($\bar{x}_{18–34}=5.3 \pm 1.3$; $\bar{x}_{55+} =5.5 \pm 1.4$; $p < 0.01$) food has more nutritional value. According to a review article [98], younger people indeed tend to be less supportive of localness. They discuss that older people may have stronger ties to the area, which makes them receptive to local food. However, the benefits of local food are not always straightforward and depend on the transport and processing factors [99]. Another study suggested that seasonal food was considered "typical" or "very typical" in the purchasing decisions of 83 % of 35–39-year-olds, compared to only 59 % of 18–24-year-olds [100]. Similarly, in the present study, 94 % of 55+ year-olds considered seasonal food to be better, compared to 86 % of individuals aged 18–34, with a significant difference of 8 % (H3 in Appendix A6). These differences may be influenced by increased health values as well as other factors, such as general convenience.

Based on the country (Appendix A5), Italian consumers generally tended to evaluate health dimensions higher ($\bar{x}_{\text{Italy}}=5.8 \pm 1.1$; $\bar{x}_{\text{Sweden}} =5.5 \pm 1.3$; $p < 0.001$) than Swedes. This trend is somewhat surprising, as the M-POHL Health Literacy Population Survey 2019–2021 (HLS19) showed that in Italy, on average, slightly less than half of respondents

Table 2
Socio-demographical distribution of the participants in the Study 2.

Characteristics		Total (N)	Italy (%)	Sweden (%)
Participants		926	51.8	48.2
Gender	Women	459	50.0	49.1
	Men	467	50.0	50.9
Age group	18–34	302	33.1	32.1
	35–54	319	34.4	34.5
	55+	305	32.5	33.4
Diet habits	Omnivores	556	56.7	63.7
	Diet-conscious	370	43.3	36.3

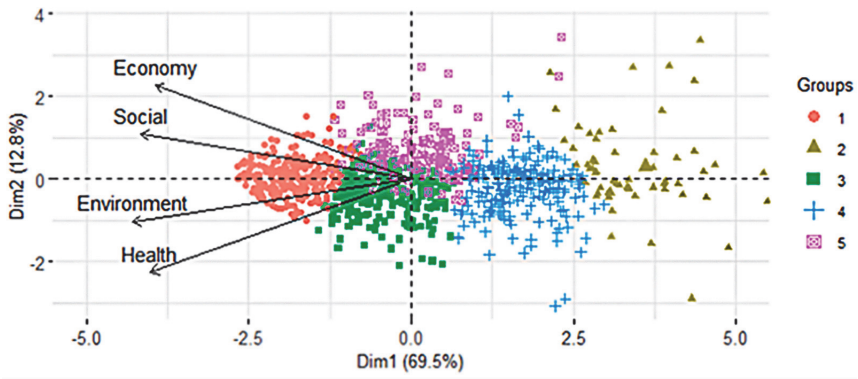

Fig. 2. Clusters and correlations with sustainability dimensions. Variance explained by the component indicated on the axis in brackets.

(43 %) had at least sufficient health literacy [101]. The same study showed higher health literacy (at least 55 % sufficient) in Norway – a Scandinavian country geographically and culturally close to Sweden. The HLS19 survey was not conducted in Sweden, although similar measurement tools have been tested there. For example, another tool HLS-EU-Q16 showed at least 71 % had sufficient health literacy [102]. However, I noted that the importance of health topics can vary. For example, Italians leaned to have a significantly higher agreement ($\bar{x}_{Italy}$=5.9 ± 1.0; $\bar{x}_{Sweden}$ =5.1 ± 1.4; $p < 0.001$) in "potential health benefits of the product are important when making the purchasing decision" (H2). Furthermore, this statement caused the greatest demographic disagreement with 68 % of Swedes and 94 % of Italians agreeing with H2 (resulting in a significant difference of 26 %, Appendix A6). On the examples of chewing gum [103] and fish [104], Italians showed more interest in nutritional information than Swedes – thus, the context matters. However, it could also be that cultural variations in the country-of-origin image of certain products influence the complexity of consumer decisions, such as through perceptions of product safety, freshness [20], and, consequently, nutritional value.

Italians tended to assess the economic dimension higher ($\bar{x}_{Italy}$=5.8 ± 1.0; $\bar{x}_{Sweden}$ =5.6 ± 1.2; $p < 0.001$) than Swedes. Although financial literacy in Sweden is generally higher than in Italy [105,106], the knowledge may differ by a specific topic. For example, previous research suggests that Italian people were more likely knowledagble about inflation compared to Swedes since they experienced it recently at the time of the study [106]. Although I did not examine knowledge of various economic issues, but rather opinion, I concluded that perception of these topics may be related to personal experience. European Banking Federation report [107] shows that Italy has 475 banking institutions as of 2020, making them fourth in the EU, compared to Sweden with 154 institutions. This may be one of the reasons Italians tended to rate the importance of the capacity of financial institutions (EC4) higher ($\bar{x}_{Italy}$=5.6 ± 1.0; $\bar{x}_{Sweden}$ =5.2 ± 1.1; $p < 0.001$). Another possibility is that there may have been higher social desirability bias. A cross-country study (incl. Italy and Sweden) on consumer innovativeness showed that, compared to the other 15 countries, Italians highly overestimated their innovativeness in adopting new products [108]. While I covered the topic of innovation in relation to economic productivity (EC2), Italian respondents may also have been biased to show their greater ($\bar{x}_{Italy}$=5.8 ± 1.0; $\bar{x}_{Sweden}$ =5.4 ± 1.2; $p < 0.001$) openness to development. It would be interesting for future studies to use this scale in conjunction with behaviour research to confirm if there was an attitude-behaviour gap as well.

The environmental and social dimensions did not differentiate between countries as much as I had assumed. The Eurobarometer report found that Swedes prioritised environmental protection highest in the EU, while Italians ranked it low [56]. Further, Italians considered "social Europe" the least important among the EU27 [57]. However, some studies imply otherwise. Researchers have shown that Spain has the highest environmental and social sustainability concerns in terms of food production, and Sweden has the lowest [93]. Although there were no corresponding data for Italy, I assumed that Italy and Spain may be similar in this regard because of their geographical and cultural proximity. In this study, Italian respondents also evaluated environmental ($\bar{x}_{Italy}$=5.9 ± 1.1; $\bar{x}_{Sweden}$ =5.8 ± 1.3; $p < 0.05$) and social ($\bar{x}_{Italy}$=6.0 ± 1.1; $\bar{x}_{Sweden}$ =5.8 ± 1.3; $p < 0.001$) dimensions slightly higher than their Swedish counterparts. However, further research is necessary to determine the underlying reasons. Another question is whether there could also be differences in consumer perception across geographical regions within the same country, as suggested by previous research [20], though this was not investigated here.

5. General discussion

The four-dimensional model demonstrated good fit, serving as the framework for the measurement tool. Consequently, the study constructed and validated a four-dimensional measurement tool (SDPS) for sustainability perception, proving its applicability across diverse consumer groups and highlighting significant contrasts among sustainability dimensions. This framework not only outlines the environmental, economic, social, and health dimensions but also highlights their interconnectedness [49]. The tool's robustness enables a nuanced understanding of sustainability, providing insights into the factors influencing perceptions and its demographical variations [8,10], potentially affecting behaviours [18,20–22].

The environmental dimension exhibited the highest levels of agreement among the sustainability dimensions, highlighting its significance in sustainability discussions. This aligns with previous studies suggesting that consumers predominantly associate sustainability with the environmental aspect [15–17]. However, the health dimension garnered less agreement, particularly among specific clusters such as Health Neutralists. This further confirms that consumers can have significantly varied perspectives on sustainability dimensions [12–17].

Cluster analysis also revealed demographic influences on sustainability perceptions. For example, younger consumers in the Health Neutralists cluster exhibited lower concern for health-related sustainability compared to older consumers, such as Green Health Advocates. Similarly, male respondents tended to place less emphasis on social sustainability, suggesting a need for strategies that focus on enhancing male engagement with social issues. These findings align with research suggesting that demographic factors such as age, gender, and dietary habits can influence sustainability perceptions [12,13,66,67].

The interconnected nature of sustainability dimensions could have resulted the Sustainability Conscious cluster, which showed high levels of agreement across all dimensions. For instance, environmental concerns may foster stronger perceptions of other dimensions, as suggested by studies on consumer behaviour [17]. The environmental aspect likely shapes broader perceptions of sustainability – for example organic products often are associated with health benefits [12]. Conversely, the Sustainability Sceptics group, which exhibited lower overall agreement with sustainability dimensions, highlights the potential for scepticism in one area to inhibit agreement across other dimensions. This finding is consistent with research suggesting that some consumers struggle to trust sustainability messaging due to information overload or confusion about the authenticity of claims [109–111]. Therefore, transparency [109,112] about sustainability topics is vital to bridging these gaps and reshaping consumer perceptions across all dimensions.

Overall, the study underscores the need to recognise the multifaceted nature of sustainability challenges [8,10]. Various factors shape the perception of sustainability dimensions — for instance, perceived behavioural control and social norms influence the social aspects, while information availability drives environmental concerns [113]. Additionally, marketing elements (e.g. label, brand), sensory cues (e.g. appearance, texture) and psychological factors (e.g. socio-cultural effects, lifestyle) further shape the perception of sustainable decisions in real-life contexts [20]. By considering these diverse influences, a more comprehensive approach to promoting sustainable behaviours across different groups can be developed.

5.1. Theoretical implications

The findings from this study have significant theoretical implications for understanding consumer perceptions of sustainability dimensions, expanding on the previous literature. The Sustainable Development Perception Scale (SDPS) introduces a robust, multidimensional framework encompassing environmental, economic, social, and health dimensions. It addresses the gap in research that needs to transition from one-dimensional to a multidimensional approach [8,10]. Therefore, it is appropriate to expand the sustainability model originally derived from the UN's three-dimensional framework, which has been used in recent scale development studies such as ASD [38] and SCQ [39].

Including health as a distinct dimension acknowledges the complex ways health issues intersect with environmental, economic, and social factors. Criticism has been directed at the SDGs for having only one goal (SDG 3) focused on health, which makes it challenging to link health to other sustainability goals [25]. Moreover, concerns have been raised that SDG 3 fails to comprehensively measure health both objectively and subjectively, representing a missed opportunity to reshape perceptions of health [114]. This is particularly significant, given the varied ways consumers perceive health concerns in relation to sustainable choices. For example, the Health Green Advocates cluster highlighted the health more comprehensively within sustainability discussions. By providing a balanced, four-dimensional scale, this study advances the theoretical landscape and enhances comparability across dimensions.

Identifying distinct consumer clusters—Sustainably Conscious, Sustainability Sceptics, Green Health Advocates, Moderate Supporters, and Health Neutralists—highlights heterogeneity in consumer attitudes toward sustainability. This heterogeneity reinforces the need for nuanced interventions and aligns with existing research on diverse sustainability perspectives [12–17]. By addressing the varied dimensions of sustainability and acknowledging the diverse perspectives of consumer groups, this approach offers a deeper understanding of sustainability perceptions.

5.2. Managerial implications

The SDPS serves as a practical tool for policymakers and businesses to design targeted interventions tailored to the diverse needs of consumer groups. Since there is no "one-size-fits-all" approach to sustainability communication, it must be tailored to various consumer groups according to their knowledge, attitudes, and other factors [115]. Previous studies highlight the importance of exploring consumers' nuanced perceptions and priorities regarding sustainability to develop more targeted and impactful strategies [12,18,115].

One of the most significant differences found was between diet-conscious individuals and omnivores, especially in the social and environmental dimensions, highlighting the need for tailored strategies. Policymakers could design educational campaigns that raise awareness about the environmental and social impacts of dietary choices. However, while some consumer groups respond well to sustainability benefits, others may be more motivated by hedonistic rewards [116], requiring additional incentives like discounts for sustainable [117] or taxes on non-sustainable [118] choices. Moreover, localised campaigns that account for cultural preferences are essential. For example, notable differences between Italy and Sweden in how health benefits influenced purchasing decisions (item H2) highlight the need for culturally tailored messaging. Collaborating with local health experts to adapt campaigns to these contexts could help bridge disparities and enhance effectiveness. As previous studies suggest, sustainable products become more relevant to consumers when they are connected to cultural associations [109,119].

Businesses can leverage insights from this study to create transparent and authentic communication strategies that resonate with their target demographics while making a genuine contribution to sustainability efforts. Aligning market strategies with consumer expectations and behaviours is crucial for success [20]. For instance, local sourcing tends to resonate more with older consumer groups. For younger consumers (Health Neutralists; most likely 18–34-year-olds), companies should focus on providing information about the environmental and social impacts of their local products, whereas for older consumers (Health Advocates; less likely 18–34-year-olds), emphasising how sourcing practices contribute to both personal health and environmental benefits can be more effective. To achieve this, businesses should provide clear information about their practices, empowering consumers to make informed, sustainable purchasing decisions [109,110,112]. Genuinely engaging in sustainable practices, rather than relying on superficial marketing tactics, can build long-term brand loyalty and motivate consumers to prioritise global sustainability goals [120].

Finally, the study underscores the importance of education [13,15,111,121] as a key strategy for shifting consumer perspectives on sustainability. For example, targeted educational campaigns could focus on raising awareness about the social aspects of sustainability among men, who tend to exhibit lower engagement with this dimension. Similarly, health campaigns could be designed to appeal more to younger consumers by linking health concerns with environmental impacts, thereby broadening their perception of sustainability. These initiatives can help create a more informed and engaged consumer base, increasing the likelihood of making sustainable choices.

5.3. Limitations and future research

It must be noted that the perception of various sustainability dimensions is often a complicated combination of different factors, not solely about knowledge. First, it is important to consider the potential influence of social desirability bias when using self-report tools, which may contribute to the high level of agreement observed in the scale. At the same time, social desirability is also a part of perception. Knowing that there is often an attitude-behaviour gap when it comes to sustainability issues, this may be one of the factors behind this phenomenon. It would be interesting to compare this scale with actual behavioural data. This brings us to a second point – future studies should incorporate additional tools to deepen understanding of perception and its interrelationship with other external factors. In the current study, other potential external factors influencing the results were solely discussed

based on previous literature, rather than empirical data. Using SDPS as a tool to correlate different datasets and to find interesting relationships (e.g. sustainability and purchase decisions, sustainability and sensory perception) would help in understanding the underlying factors shaping the perceptions. This can contribute to strategies and interventions aimed at promoting sustainable behaviour among different consumer groups.

The formulation of the study plan entailed critical decisions that could have potentially limited the outcomes. Starting from the development of the scale, statements were constructed based on similar previous studies while striving to be as comprehensive as possible. However, it can be questioned whether this scale encompasses all essential aspects of sustainability perception. Nonetheless, factor analysis is a robust and sophisticated method that enabled the selection of statements with demonstrated validity for inclusion in the final SDPS as a four-dimensional model. The scale underwent validation with multiple sample sets to ensure the comparability and reliability of results for both the current and future studies. Another limitation stemming from the research plan is the study's confinement to European countries. Expanding the scope could provide valuable insights for consumer education globally. Given that SDPS allows for comparative applications, future studies could explore a broader range of culturally diverse countries [9]. For example, non-Western cultures tend to overconsume, whereas there is increasing awareness of overconsumption in Western cultures [122,123]. Additionally, sustainability reports often have a different focus in developed and developing countries, with developed countries emphasising the environmental dimension and developing countries focusing on the social dimension [124]. This suggests that consumer perceptions in these regions may also differ. Furthermore, in large countries like India, consumer decisions can vary significantly across geographical regions due to factors such as regulatory norms, economic conditions, and other local influences [20]. Expanding on this, we might hypothesize that a broader range of perspectives, influenced by cultural differences, remains uncovered.

6. Conclusions

The current study developed and validated 22-item SPDS covering perceptions of environmental, economic, social and health sustainability. Further, confirmed that the scale is generalisable in countries tested. In this study, SDPS identified five consumer clusters which provides valuable insights into the diverse perspectives on sustainability. Sustainably Conscious primarily consisted of Italian respondents who showed higher agreement levels than Swedes, particularly in terms of health and economics. Despite their lower health and financial literacy, other factors (e.g. recent experiences) could have influenced Italians' perception which should be further investigated. Sustainability Sceptics, consisting mostly of omnivores and men, displayed the lowest agreement levels. Findings from this study, along with previous research, indicate a connection between plant-based dietary habits and social/environmental concerns, with men exhibiting lower agreement mainly with social statements. Previous literature confirms that a plant-based diet is often motivated by various sustainability dimensions. Further, this may suggest a need for communication that breaks stereotypes and engages men more in the social dimension. Health Neutralists, predominantly composed of the youngest age group, demonstrated lower agreement with health. This suggests that younger consumers may prioritise other sustainability dimensions over health considerations, which may change with age. In contrast, Green Health Advocates, including older age groups, showed stronger agreement with the health dimension compared to Moderate Supporters. The latter included more omnivores and younger individuals, resulting in a more neutral perception. These results highlight the perceptual differences in sustainability among various consumer groups, underscoring the need for tailored approaches in sustainability communication.

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CRediT authorship contribution statement

Helen Vaikma: Writing – review & editing, Writing – original draft, Visualization, Validation, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization.

Declaration of competing interest

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Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.sftr.2025.100616.

Data availability

Data will be made available on request.

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Appendix 4

Article IV

Vaikma, H., Almli, V. L., Harwood, W., Kern, M. (2025). Consumer perceptions of sustainability towards ingredients, packaging, labelling, and storage conditions in milk, burger products, and plant-based alternatives: A study in Sweden and Italy. Future Foods, 11, 100635.
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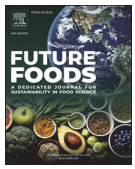

Consumer perceptions of sustainability towards ingredients, packaging, labelling, and storage conditions in milk, burger products, and plant-based alternatives: A study in Sweden and Italy

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Sustainable food

ABSTRACT

Sustainability increasingly shapes consumer attitudes and purchasing decisions, but perceptions of what constitutes sustainability vary. This study, conducted in Sweden and Italy in 2022 with 600 respondents, examined sustainability in a multidimensional manner (across social, environmental, economic, and health dimensions) for burgers and milk. Using the Sustainability Dimensions Perception Scale (SDPS) and a Choice-Based Conjoint (CBC) analysis, the research found that the food ingredient's origin (animal vs. plant) was the most important characteristic for defining a sustainable product, particularly for burgers. Plant-based options were associated with higher perceptions of social, environmental, and health dimensions in both dairy and burger categories. Packaging, labelling and storage conditions were generally perceived to be less important for sustainability perception, and associations with different sustainability dimensions depended on the specific product category (i.e. milk or burger). In addition, five consumer segments were identified in the dairy and burger categories: "Animal-based food", "Local label", "Label importance", "Plant-based food", and "Cardboard container", each reflecting diverse priorities in sustainability. As a result, this study addressed the general sustainable attitudes and product-specific attitudes, building on a multidimensional framework. This study offered valuable insights for understanding consumer preferences and developing strategies to guide them toward more sustainable choices.

Introduction

Sustainability generally means meeting our present needs without jeopardising the future (Brundtland, 1987). It also relates to the Sustainability Development Goals from the 2030 Agenda, such as to "end hunger, achieve food security and improved nutrition, and promote sustainable agriculture" (United Nations General Assembly, 2015). Sustainability is a broad concept that includes many areas like economic, social, and environmental factors (United Nations General Assembly, 2015). It involves various dimensions beyond just the environmental aspect that it's most commonly associated with (Gao et al., 2020; Stancu et al., 2020).

Food production plays a major role in global sustainability challenges. On one hand, the food industry is a major greenhouse gas emitter (European Environment Agency, 2018; OECD/FAO, 2022). In 2019, agriculture made up 11 % of global greenhouse gas emissions (GHGE), with livestock being a significant source of CO_2 production and ruminants, manure, and food waste being major sources of methane emissions (OECD/FAO, 2022). Meat and dairy products alone account for about 24 % of the environmental impact of food consumption in the EU

Abbreviations: PB, Plant-based; AB, Animal-based; GHGE, greenhouse gas emissions; SDPS, Sustainability Dimensions Perception Scale; CBC, Choice-Based Conjoint (analysis); UHT, Ultra High Temperature (processing); AF, consumer segment titled "Animal-based food"; LL, consumer segment titled "Local label"; LI, consumer segment titled "Label importance"; PF, consumer segment titled "Plant-based food"; CC, consumer segment titled "Cardboard container"; n.s., not significant.

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(European Environment Agency, 2018). On the other hand, as the world population grows, the dietary pressure increases (Godfray et al., 2010), making it harder to ensure enough food for everyone. OECD/FAO (2022) reports that the average per capita protein consumption will increase by 4 % by 2031, which may raise the demand for plant-based (PB) proteins, along with the growing challenges to various sustainability issues. All in all, our food choices have an important effect on sustainability. A systematic review on the environmental impact of human diets has demonstrated that a PB diet such as veganism has the lowest impact on greenhouse gas emissions (GHGE), but reducing meat and dairy consumption can also help reduce GHGEs (Chai et al., 2019). While the food ingredients used daily have a significant impact on the environment, it is not the only dimension to consider. Many other sustainability aspects, such as health (Giacalone et al., 2022; Macdiarmid, 2022), food affordability (Fresán et al., 2020; Siqueira et al., 2021) and animal welfare (Fresán et al., 2020; Knaapila et al., 2022), are also influenced by the food ingredient choices we make.

Another major issue with the food industry is waste, including both food and packaging waste. For instance, approximately 931 million tons of food are wasted each year (United Nations Environment Programme, 2021). This leads to various environmental, social, and economic issues (United Nations Environment Programme, 2021), such as increased GHGE emissions, resource depletion, reduced food availability, and additional costs for consumers and retailers (Conrad, 2020; de Gorter et al., 2021; Tóth and Zachár, 2021; Wunderlich, 2020). Furthermore, 14 % of food is lost between post-harvest and retail (FAO, 2019). Food system efficiency should be improved to reduce food waste and loss (Manzoor et al., 2024). Food production also results in significant amounts of packaging waste. Food production also creates a significant amount of packaging waste. Over 2/3 of the packages produced worldwide are used by the food industry (Piergiovanni and Limbo, 2016), leading to issues with recycling and food safety. Currently, plastics make up the largest share (44.2 %) of global packaging material market, while paper/cardboard packages have the second largest (33.2 %) share (Statista, 2023). However, paper/cardboard packaging is considered the most sustainable in terms of life-cycle impact due to its biodegradability and high recycling rates (Otto et al., 2021), while >60 % of plastic waste is from packaging and only 40 % of it gets recycled (European Commission, 2018).

To tackle the sustainability challenges associated with food production, first, a reduction in the consumption of animal proteins and a switch to alternatives is encouraged (European Environment Agency, 2018). Fortunately, there has been a significant shift in consumer demand for PB alternatives to traditional animal-based (AB) products attributed to various sustainability reasons, often related to concerns about health, animal welfare, and the environment (Adamczyk et al., 2022; Bryant, 2022; Fresán et al., 2020; Good Food Institute, 2022; He et al., 2020; Jahn et al., 2021; Knaapila et al., 2022; Perez-Cueto, 2020). This trend is not limited to vegans and vegetarians but also includes flexitarians, i.e. individuals who consciously reduce their meat and dairy consumption (de Boer et al., 2014; Kemper et al., 2023). Currently, PB meat and milk alternatives are among the largest markets in the PB alternative sector (Good Food Institute, 2022; Smart Protein, 2021) and are estimated to grow at a compound annual growth rate (CAGR) of 10.7 % for dairy and 11.3 % for meat between 2024 and 2029 (Mordor Intelligence, 2024, 2025). Although PB alternatives consumption has increased, many consumers are still hesitant to shift towards these products due to barriers such as high prices (Adamczyk et al., 2022; Good Food Institute, 2022), specific taste properties (Adamczyk et al., 2022; Jahn et al., 2021), food neophobia (Jahn et al., 2021), health scepticism, limited availability, preparation difficulties, social barriers (He et al., 2020; Jahn et al., 2021), limited knowledge (He et al., 2020).

Second, to address food waste issues and their associated sustainability challenges, ensuring optimal storage conditions is essential (Ladha-Sabur et al., 2019; Zanoni and Zavanella, 2012). Storing food at lower temperatures generally extends the shelf life of products because of slower spoilage; however, there are challenges as well. For example, refrigerating can extend shelf life but consumes more energy than ambient storage (Ladha-Sabur et al., 2019), and freezing, which can extend shelf life even further, requires more energy than refrigeration (Zanoni and Zavanella, 2012). Third, another approach to tackle the issue of food waste, is to offer more sustainable packaging solutions (Almli et al., 2018; Otto et al., 2021) that are effective for prolonging food storage and are also safe for consumers (e.g. no compound migration) and the environment (e.g. biodegradable options).

Lastly, to communicate the sustainability benefits of various products, many producers also use various sustainability labels on their products. For example, Fair Trade is attributed to social and economic dimensions (European Commission, 2008), and organic to various environmental aspects (European Commission, 2023b). However, the food industry uses a wide range of sustainability labels, including unregulated and self-declared labels, which lead to confusion and scepticism among consumers (Rossi and Rivetti, 2023). As a result, many consumers often ignore sustainability-related labels (Cho and Taylor, 2020; Cook et al., 2023).

Purpose of the study

It is important to emphasise that concern for sustainability does not always translate into consumer behaviour. For example, consumers who express pro-environmental attitudes might not always buy products with eco-labels or organic items (Kim and Lee, 2023; Tandon et al., 2020). Similar patterns can be seen with social (ethical) attitudes and purhcasing Fair Trade products (Köksal Araç and Çabuk, 2023; Kossmann et al., 2021). Additionally, different aspects of sustainability influence consumers in various ways. For instance, Uliano et al. (2024) demonstrated that consumers were more willing to pay for functional snacks based on health considerations rather than environmental factors. Therefore, it is essential to understand the types of sustainable choices consumers make in different contexts, such as packaging or ingredients. Further, it is crucial to communicate sustainability to consumers in a way that encourages people to make more sustainable choices. Particularly given that consumers can have different perceptions of what sustainability means to them (Camilleri et al., 2023; Gao et al., 2020; Sánchez-Bravo et al., 2020, 2021).

According to the Theory of Planned Behaviour (Ajzen, 1985), behavioural intention is influenced by personal attitudes, subjective norms, and perceived behavioural control. Building on this, decisions about what makes a product sustainable are influenced by various factors, such as barriers and motivators (attitudes toward the products), social and cultural expectations (subjective norms), and how accessible and available these products are (perceived behavioural control). Therefore, multiple factors can influence behaviour. This study primarily addressed the attitudes, assessing the cognitive components through consumers' knowledge and understanding of sustainable product characteristics. However, the discussions also addressed other possible factors based on literature and reports, such as subjective norms specific to countries like Italy and Sweden, as well as the availability of these product concepts in the market.

Tripartite model of attitude was developed by Rosenberg and Hovland (1960) and was subsequently expanded and applied in further research (Ajzen, 2005; Baldi et al., 2021). According to the model, the affective (feelings) and cognitive (understanding) components shape the attitude, which in turn influences behaviour (actions). Several studies have explored sustainable behaviour using either self-reported data gathered through questionnaires (Cesarina Mason et al., 2022; Khan et al., 2020; Lavuri et al., 2023), interviews (Čiarnienė et al., 2023; Hageman et al., 2024; Pradeep and Pradeep, 2023), and focus groups (Fraj-Andrés et al., 2022; Kremel, 2024; Mielinger and Weinrich, 2024), or secondary sources collected through loyalty cards and supermarket purchasing data (Carpinelli et al., 2022; May and Fearne, 2024; Yamoah and Acquaye, 2019). However, as noted before, behavioural intention is

strongly affected by previous attitudes, thus behavioural studies do not give the full picture of how consumers perceive sustainability issues. Especially considering that different attitudes do not always lead to action. Thus, this study is designed to examine only what precedes the behaviour. Specifically, on the cognitive aspect, which studies suggest that consumers have varying levels of understanding of sustainability (Camilleri et al., 2023; Gao et al., 2020; Sánchez-Bravo et al., 2020, 2021).

This study uses different methods to understand how people view sustainable products. First, the Sustainability Dimensions Perceptions Scale (SDPS) by Vaikma (2025) was used to identify what are the important sustainability dimensions (i.e. environment, economic, social, health) based on self-report values. Second, a Choice-Based Conjoint study (CBC) was conducted to measure how consumers perceive sustainability in specific products. Nonetheless, combining a perceptual sustainability scale with a conjoint study is not an entirely new approach. Barcellos et al. (2011) combined the New Environmental Paradigm scale and conjoint analysis to investigate the gap between environmental attitudes and purchasing behaviour. However, their focus was on pig production systems, while this research examines milk and burger products, particularly regarding different sustainability aspects. Instead of focusing on consumer behaviour, it uses the CBC to gain deeper insights into consumer attitudes. By investigating the SDPS and CBC data, it is possible to investigate whether individuals' perceptions of food sustainability are similar individually and product-specifically. Recognising the potential gap in sustainability perception, the findings could present an intriguing exploration of the multifaceted nature of sustainability. To the best of the authors' knowledge, combining a multidimensional perspective of sustainability with a conjoint study is also a novel approach.

The purpose of this research was to investigate how sustainability values are expressed in product-specific situations, both individually and across different consumer segments. Specifically, identifying consumers' perceptions of sustainability dimensions in the context of milk and burgers, including their PB alternatives. Besides focusing on ingredients (AB and PB), the study also looked at packaging materials, storage conditions, and labels. To determine whether there are distinct consumer groups with different views on sustainability, the product concepts were tested among people of various demographics, such as gender, age, and dietary habits. Additionally, the study included participants from different cultural backgrounds (Italy and Sweden) to gain cross-cultural insights. The findings provide valuable information about which aspects of sustainability are most important to consumers regarding food products and whether these views differ between food categories. This can help develop communication strategies that encourage people to choose more sustainable food options.

Materials and methods

To provide a clearer overview, the study design is divided into three phases (Fig. 1). The consumer test was conducted in October 2022 over two separate data collection points. In Phase 1, Italian and Swedish respondents were contacted online to complete the socio-demographic questions and the SDPS (Vaikma, 2025). After a one-week break, Phase 2 began with the second data collection point, where the same respondents participated in the CBC study and selected the most sustainable products from a series of three options. The time interval was implemented to minimise potential bias from completing the SDPS. Incentives (app-specific coins and gift cards) were provided to encourage completion of the second part of the study. In Phase 3, data analysis was conducted, starting with an overview of both overall and country-specific perceptions based on product selections in the CBC (Chapter 3.1). This was followed by segmentation based on CBC results, with segments described through socio-demographic characteristics (Chapter 3.2), and concluding with an analysis correlating these choices with perceptions of sustainability dimensions based on the SDPS (Chapter 3.3).

Participants and socio-demographic characteristics

An online survey was conducted to gather data from adults in Sweden and Italy. These countries were chosen because earlier reports (Eurobarometer, 2020, 2021; Saschs et al., 2021) showed significant differences between Swedish and Italian respondents in how they rate the importance of different sustainability issues. The survey was presented in the primary languages of the respective countries (Swedish and Italian); however, the results were presented in English in this paper to facilitate analysis and interpretation.

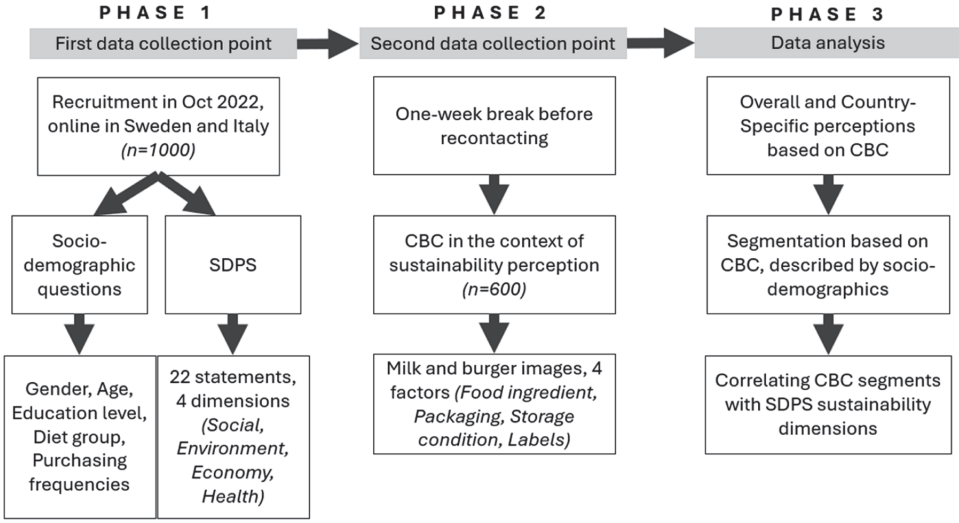

Fig. 1. Schematic representation of the study method divided into three phases. Abbreviations: CBC – Choice-Based Conjoint (analysis), SDPS – Sustainability Dimensions Perception Scale.

Participants were recruited by Dynata (Shelton CT, US) from an online panel. The study recruited 1000 respondents who were at least 18 years old, split by country, gender, and age groups. These quotas were set to ensure a balanced representation and to increase the ability to identify differences among demographic groups, as previous research suggests that demographic factors may influence understanding of sustainability (Sánchez-Bravo et al., 2020, 2021; Vaikma, 2025). After a one-week break, 600 respondents had completed the survey with the second part focusing on specific product choices.

Participants were recruited by Dynata from an online panel. Phase 1 of the study involved 1000 respondents who were at least 18 years old, divided by country, gender, and age group. These quotas were set to ensure a balanced representation and to increase the ability to identify differences among demographic groups, as previous research suggests that demographic factors may influence understanding of sustainability. Although the study aimed to capture personal opinions about sustainability, it was important to consider that previous experiences with PB products might influence responses. Participants were further asked about their highest level of education, dietary habits, and purchasing habits. Specifically, we enquired about the purchasing frequency of PB meat (incl. burgers, sausages, etc.) and PB dairy (incl. milk, yoghurt, etc.) alternatives. After a one-week break, 600 respondents had completed the survey in Phase 2 focusing on specific product choices in CBC task.

This study was carried out following the Principles of Academic Ethics by Tallinn University of Technology, which addresses ensuring the safety of research and data processing. This study does not include collecting sensitive personal data, as the survey only includes questions about sustainability perception and demographical characteristics. Regardless, responsible data management was implemented to prevent participant identification and ensure confidentiality, according to the General Data Protection Regulation (GDPR). Participants were also informed of the general purpose of the study and provided informed consent to participate in this study. All the participants were made aware that participation was voluntary, enabling them to withdraw from the study at any time.

Sustainability Dimensions Perception Scale

Consumer perceptions of sustainability were investigated using the Sustainability Dimensions Perception Scale (SDPS) published by Vaikma (2025). This consisted of 22 statements divided into four dimensions of sustainability: social, environmental, health, and economic. Although most sustainability studies utilise a three-dimensional framework (United Nations, 1992), including health as a separate dimension is relevant in this study as it is often a major motivator for consumers of meat, dairy, and PB alternatives (Giacalone et al., 2022; He et al., 2020; Jahn et al., 2021; Macdiarmid, 2022). The statements were phrased as 'I think that…' and were rated on a 7-point Likert scale (1 – 'strongly disagree', 7 – 'strongly agree'). The dimensions and statements were presented to consumers in a random order. On average, it took five minutes for respondents to complete this section.

Conjoint study

CBC analysis is a widely used method for understanding consumer preferences (Bell et al., 2020). The given task shifted from the common practice of selecting a preferred product to choosing the most sustainable option, with the aim of prioritising participants' personal views over their everyday purchasing and/or consumption habits. A similar approach has been used in previous studies, for example, on the acceptability of living conditions (Wallquist et al., 2012) and the healthiness perception of snacks (Velázquez et al., 2021). Since price is usually a key factor in food choices (Fox et al., 2021; Seubelt et al., 2022; Stewart-Knox et al., 2024), we didn't include it in the study to keep the focus on sustainability and not dilute differentiation based on price sensitivity. Also, we didn't use real products in CBC task to avoid any bias from past experiences (Nobrega et al., 2020), ensuring the comparison between countries is fair.

Participants were shown images of conceptual products specifically designed for the study by the Sono Cats Agency (Gilching, Germany). The conceptual products were presented in the form of product packaging with different labels, together with an explanatory table (Fig. 2), so that all participants could understand the differences between the products and the meanings behind the design in the same manner. The product concepts were presented in Italian or Swedish in the respective countries.

The conjoint design included four factors of two or three levels each as follows: 2 (food ingredient: animal-based/plant-based) × 2 (packaging: recycled plastic/cardboard container) × 2 (storage condition: ambient or frozen (milk or burger) /refrigerated) × 3 (labels: Fair Trade/organic/local) design for two types of products: burgers and milk. This created 24 unique combinations for each product category. The factors and options were selected based on previous sustainability studies (read also Introduction), which can be reviewed in more detail in Supplementary Table A1.

As evaluating many concepts can be tiring and lead to poor quality data (Szymkowiak et al., 2020), the number of factors and levels were limited. Based on the literature, respondents are capable of providing reliable results after completing 30 tasks and likely beyond (Bansak et al., 2018). Respondents were shown 12 sets of three images each, using the Balanced Overlap Method, which avoids repetition of concepts while tracking co-occurrences. This approach is controlled and systematic but does not involve testing every possible combination of attributes, as is done in complete enumeration methods. For each type of product, 12 sets of tasks were reviewed. Every set of three images was displayed in random order, with rotations determined by an algorithm designed to achieve a balanced arrangement of attributes. Half of the participants started with the burger task, then moved to the milk task, while the other half did the opposite. As the aim was to encourage participants to choose based on their conception of sustainability, rather than to simulate a purchase situation, there was not an option to choose "none of them" and participants were required to choose a product from each set. On average, it took approximately 7.5 min to complete the entire CBC section.

Statistical analysis

Data analysis involved only respondents who completed both Phases 1 and 2 of the study. To ensure data quality, straight-liners and speeders were excluded during the preprocessing phase of the data. Speeders were identified based on completion time thresholds established during the soft launch, which involved 10 % of the target sample size. This allowed to establish baseline metrics for reliable data collection during the full launch. The threshold for identifying speeders may vary depending on the goal, but the decision to use two-thirds of the median LOI as the cutoff aligns with industry practices and guidelines from the literature (Greszki et al., 2015). The median LOI for the Phase 2 was approximately 6 min, so those who finished in <4 min (two-thirds of the median) were excluded as it indicated insufficient engagement.

Decomposition analysis from the CBC test was performed to investigate the importance of attributes (factors) and the relative preferences of the levels. Utility coefficients were estimated using a Hierarchical Bayesian Mixed Logit Model, which used a Monte Carlo method to iterate through possible solutions to the logit equations until a reasonable but subjective level of convergence was achieved. Segmentation was performed using a Latent Class Multinomial Logit model (Hensher et al., 2015). This model assumes discrete distributions and captures possible heterogeneity through membership in various clusters, allowing the parameters to be random in each class. The models were run in Lighthouse Studio version 9.4.0 (Sawtooth Software, Sun Valley ID, US) according to Sawtooth Software, Inc. (2021a, 2021b).

Fig. 2. Example images and tables of concepts presented in the conjoint study (English translation).

Further analysis was performed using R version 4.1.1 (R Foundation for Statistical Computing, Vienna, Austria). The normality of the data was tested visually (function “ggdensity” from package ggpubr) and statistically (function “shapiro.test”), showing no normality. Statistical significance was tested using the Wilcoxon Rank Sum Test (function “wilcox.test”) for continuous data and Chi Squared test (function "chisq. test”) for count data. The relationships between sustainability dimensions and product characteristics were investigated using Spearman’s correlation (2-tailed) with IBM SPSS Statistics version 29 (International Business Machines Corporation, New York, USA).

Results

Demographics and general perception of sustainability overall and across countries

A total of 600 respondents participated in the given study. Details about the participants are shown in Table 1. The final demographic distribution of the sample group was influenced by the level of engagement of participants in completing the Phase 2 (CBC) of the study after a one-week break. Overall, respondents exhibited diverse purchasing habits for dairy, meat, and PB alternative products. This variability helps to reduce any potential bias from purchasing habits affecting the choice-based decisions.

Based on the milk category (Fig. 3), respondents thought the most important factor for a sustainable product was the food ingredient (25 % for the total sample). In the burger category, the importance of the food ingredient (37 % for the total sample) was much higher, showing a clear link between PB foods and higher sustainability. While the associations with various sustainability dimensions are explored later in Chapter 3.3, it can be suggested that consumers perceive the negative impact of AB food production on sustainability more strongly for burgers than for milk products. Further, Swedes had a bigger difference in how they valued the food ingredient for milk category compared to Italians, whereas the opposite was true for burgers (utility values in Fig. 3).

Packaging material was notably important for people when thinking about the sustainability of milk and its PB alternatives (24 % for the total sample). In Italy, milk packaging was even seen as more important than the food ingredient itself (26 % for packaging vs. 20 % for food ingredient). Overall, packaging was less important for sustainability in burgers compared to milk (13 % vs. 24 %, respectively for the total sample). Despite some differences in what factors were considered important for a sustainable product, there were many similarities in how people viewed these factors. For instance, cardboard containers were generally seen as more sustainable for packaging in both product categories (specific sustainability dimensions discussed later in Chapter 3.3).

Although storage conditions were considered least important for the milk and burger categories (13 % for the total sample in both categories), ambient (long shelf life) milk products and refrigerated (short shelf life) burgers were generally seen as more sustainable (based on

Table 1
Description of participants by proportion (%) and count (in brackets) for each country and for the total sample.

Attribute	Range	Total (n = 600)	Italy (n = 300)	Sweden (n = 300)
Gender	Women	53.2 % (319)	53.0 % (159)	53.3 % (160)
	Men	46.8 % (281)	47.0 % (141)	46.7 % (140)
Age group	18–34	24.0 % (144)	28.7 % (86)	19.3 % (58)
	35–54	38.8 % (233)	37.3 % (112)	40.3 % (121)
	55+	37.2 % (223)	34.0 % (102)	40.3 % (121)
Education level *	Low	8.0 % (48)	7.7 % (23)	8.3 % (25)
	Medium	50.5 % (303)	52.3 % (157)	48.7 % (146)
	High	41.5 % (249)	40.0 % (120)	43.0 % (129)
Diet group	Omnivore	62.2 % (373)	56.3 % (169)	68.0 % (204)
	Diet-conscious **	37.8 % (227)	43.7 % (131)	32.0 % (96)
Purchasing frequency of dairy products	Never	2.0 % (12)	2.7 % (8)	1.3 % (4)
	Less than once a month	2.5 % (15)	2.7 % (8)	2.3 % (7)
	1–3 times a month	24.5 % (147)	24.3 % (73)	24.7 % (74)
	Once a week	57.8 % (347)	51.0 % (153)	64.7 % (194)
	Multiple times a week	13.2 % (79)	19.3 % (58)	7.0 % (21)
Purchasing frequency of meat products	Never	5.8 % (35)	4.3 % (13)	7.3 % (22)
	Less than once a month	10.3 % (62)	8.3 % (25)	12.3 % (37)
	1–3 times a month	36.2 % (217)	35.7 % (107)	36.7 % (110)
	Once a week	43.7 % (262)	46.3 % (139)	41.0 % (123)
	Multiple times a week	4.0 % (24)	5.3 % (16)	2.7 % (8)
Purchasing frequency of PB dairy alternatives	Never	23.0 % (138)	13.3 % (40)	32.7 % (98)
	Less than once a month	15.8 % (95)	17.3 % (52)	14.3 % (43)
	1–3 times a month	18.3 % (110)	22.7 % (68)	14.0 % (42)
	Once a week	17.8 % (107)	16.7 % (50)	19.0 % (57)
	Multiple times a week	25.0 % (150)	30.0 % (90)	20.0 % (60)
Purchasing frequency of PB meat alternatives	Never	33.5 % (201)	38.0 % (114)	29.0 % (87)
	Less than once a month	14.7 % (88)	16.7 % (50)	12.7 % (38)
	1–3 times a month	11.3 % (68)	14.0 % (42)	8.7 % (26)
	Once a week	16.8 % (101)	18.7 % (56)	15.0 % (45)
	Multiple times a week	23.7 % (142)	12.7 % (38)	34.7 % (104)

* Low – primary and basic school; Medium – high and vocational school; High – bachelor's, master's and doctorate degree).
** Increased PB or only PB preferences in dietary choices, such as flexitarians, vegetarians and vegans.

utility values in Fig. 3). Furthermore, while both Italian and Swedish consumers associated ambient-stored milk and PB alternatives more likely with sustainability, in the burger category, Italians leaned towards frozen burgers, whereas Swedish consumers showed no clear tendency.

Overall, labelling was the third most important factor for milk products and the second most important for burgers (22 % for both categories). Participants generally thought that local labels indicated a more sustainable product, while Fair Trade was the least associated with sustainability. This view was similar in both countries, with links to sustainability explained in Chapter 3.3.

Different perceptions of sustainability across segments

The analysis identified five different segments of consumers (Fig. 4). Each group made up between 11 % and 35 % of the total sample size. Two of the most distinctive segments were based on the food ingredient perception. PF ("Plant-based food") consumers tended to link sustainability with plant-based products, valuing these ingredients highly (importance 54 % for milk and 63 % for burgers). This segment shared 84 % of its members between milk and burger categories and indicated that they are more likely diet-conscious, purchase less meat, and purchase more PB alternatives (Supplementary Tables A2, A3). Conversely, AF ("Animal-based food") consisted mainly of consumers considered animal-based products as more sustainable (food ingredient importance was 58 % for milk and 63 % for burgers in Fig. 3). Furthermore, 75 % 75 % of respondents in this group were common to both milk and burger categories. Members of AF were more likely to have omnivorous dietary habits and were less inclined to buy plant-based options (Supplementary Tables A2, A3). Additionally, this group tended to be significantly more likely to be Swedish, men, and over 55 years old.

LL ("Local label") consumers mainly prioritised local labels, with label importance 52 % for milk and 47 % for burger category, sharing 54 % of the respondents between these segments (Fig. 4). These consumers were more likely to frequently purchase AB product – significantly more dairy in the milk segment and significantly more meat in the burger segment (Supplementary Tables A2, A3).

For the two other groups, less than half of the respondents were shared between the milk and burger categories, indicating specific associations to each product category and making it challenging to describe these segments overall. First, LI ("Label importance") segment saw labelling as the most crucial sustainability factor. However, they didn't have a strong preference for any particular label, as shown by the low utility scores in Fig. 4, though they tended to lean towards organic labels. These consumers were more likely to be Italians (significant for the milk category) and purchased fewer PB meat alternatives (significant for the burger category) (Supplementary Tables A2, A3).

Secondly, CC ("Cardboard container") consumers mainly chose cardboard containers as sustainable products, with 60 % importance for milk and 59 % for burgers (Fig. 4). Similarly to LI segment, respondents in the milk category were significantly more from Italy, but in the burger category, they were also significantly more frequent dairy and meat purchasers (Supplementary Tables A2, A3). Interestingly, despite their frequent purchases of AB products in real life, they prioritised packaging over food ingredients, giving the latter the least importance (7 % for milk and 10 % for burgers).

Correlations between sustainability dimensions and product characteristics based on segments

People who viewed PB milk alternatives as more sustainable showed a strong correlation to social ($\rho = 0.90$, $p < 0.05$) dimension, and a moderate correlation with the environmental ($\rho = 0.70$, n.s.) and health ($\rho = 0.60$, n.s.) dimensions (Fig. 5). The group focusing milk alternatives in sustainability (segment PF in Fig. 4) likely considered these dimensions most important. In contrast, those who prioritised AB milk as the most sustainable (segment AF in Fig. 4) had negative correlations with the social ($\rho = -0.90$, $p < 0.05$), environmental ($\rho = -0.70$, n.s.), and health ($\rho = -0.60$, n.s.) dimensions (Fig. 5). Similar trends in the perception of the food ingredients were also observed for burgers. Social, environmental, and health factors showed strong negative correlations with AB burgers (social: $\rho = -0.90$; $p < 0.05$; environment: $\rho = -0.90$, $p < 0.05$; health: $\rho = -0.80$, n.s.), and positive correlations with

		Total		Italy		Sweden	
MILK CATEGORY							
Factor	Level	Importance	Utility	Importance	Utility	Importance	Utility
Food Ingredient	Plant-based	**25%**	-0,1	20%	0,1	**29%**	-0,4
	Animal-based		0,1		-0,1		0,4
Pack-aging	Recycled plastic	24%	-0,8	**26%**	-0,9	21%	-0,8
	Cardboard container		0,8		0,9		0,8
Storage Condition	Refigerated	13%	-0,4	14%	-0,5	12%	-0,2
	Ambient		0,4		0,5		0,2
Labels	Organic	22%	-0,1	22%	-0,1	22%	-0,2
	Fair Trade		-0,6		-0,5		-0,7
	Local		0,7		0,6		0,9
BURGER CATEGORY							
Factor	Level	Importance	Utility	Importance	Utility	Importance	Utility
Food Ingredient	Plant-based	**37%**	0,5	**34%**	1,1	**40%**	-0,1
	Animal-based		-0,5		-1,1		0,1
Pack-aging	Recycled plastic	13%	-0,5	15%	-0,5	11%	-0,4
	Cardboard container		0,5		0,5		0,4
Storage Condition	Refigerated	13%	0,3	15%	0,6	12%	0,0
	Frozen		-0,3		-0,6		0,0
Labels	Organic	22%	-0,2	21%	-0,1	23%	-0,3
	Fair Trade		-0,7		-0,5		-0,9
	Local		0,9		0,6		1,1

Fig. 3. Comparison of importance (highest % of the subgroup in bold) and utility levels by product category and country. Negative utilities indicate factor levels perceived as less sustainable, while positive utilities indicate factors perceived as more sustainable.

PB burger alternatives (social: $\rho = 0.90$; $p < 0.05$; environment: $\rho = 0.90$, $p < 0.05$; health: $\rho = 0.80$, n.s.). Additionally, the correlations with health and environmental dimensions were stronger in the burger category compared to the milk category, where the same dimensions showed moderate correlations.

While cardboard containers are generally seen as more eco-friendly, especially by the CC group (Fig. 4), various sustainability dimensions seem to play a role (Fig. 5). In the case of the milk category, the cardboard containers were preferred, showing a moderate correlation ($\rho = 0.60$, n.s.) with the environmental dimension. The social dimension also showed a moderate correlation ($\rho = 0.50$, n.s.) with choosing cardboard packaging. Even though the CC group for the burger category also perceived cardboard as more sustainable (Fig. 4), the correlating dimensions were not the same as for the milk category. The economic aspect seemed to be the most important association ($\rho = 0.67$, n.s.) in choosing cardboard products (Fig. 5).

None of the segments prioritised the storage condition, although LL (milk, burger) and LI (burger) considered it the second most important (Fig. 4). A milk product stored at room temperature with a long shelf life was generally seen as more sustainable than the refrigerated option. The tendency towards ambient conditions showed a moderate correlation to health ($\rho = 0.70$, n.s.), environmental ($\rho = 0.60$, n.s.) and economic ($\rho = 0.50$, n.s.) dimensions (Fig. 5). In contrast, a refrigerated burger with a shorter shelf life was seen as more sustainable than a frozen one, and this was linked to social ($\rho = 0.60$, n.s.) and environmental dimensions ($\rho = 0.60$, n.s.).

Mostly, the local label was chosen as the most sustainable option with small differences across segments (except for LI, Fig. 4). For the milk category, it showed a moderate negative correlation with the economic ($\rho = -0.60$, n.s.) and social ($\rho = -0.50$, n.s.) dimensions (Fig. 5). This suggests that consumers do not strongly link the local origin of the product with economic and social aspects as much as they might with environmental or health factors. Interestingly, for the burger category, the local label showed a significantly strong negative relationship with the health dimension ($\rho = -0.90$, $p < 0.05$), while the correlations with the health dimension were positive for organic ($\rho = 0.70$, n.s.) and Fair Trade ($\rho = 0.80$, n.s.) labels. Additionally, the organic label for milk showed a moderate positive relationship with the economic dimension ($\rho = 0.60$, n.s.), whereas for the burger category, it had a moderate negative correlation ($\rho = -0.56$, n.s.).

Discussion

Food ingredient

More people are becoming aware of the negative impacts of AB proteins and are seeking alternatives (Bryant, 2022). Past research has shown that concerns about animal welfare (as part of the social dimension), health, and the environment (Adamczyk et al., 2022; Fresán et al., 2020; Good Food Institute, 2022; He et al., 2020; Jahn et al., 2021; Knaapila et al., 2022; Perez-Cueto, 2020) are key reasons why consumers prefer PB alternatives. For example, a focus group study by Beacom et al. (2022) the environmental concerns motivate people to switch to PB proteins, while another study found that burgers made from peas and algae were seen as healthier than beef burgers (Michel et al. 2021). Therefore, choosing PB ingredients for milk and burgers linked to environmental, social and health dimensions are confirmed by previous findings. Negative correlations in the same dimensions with AB ingredients might indicate that some people are less aware of these issues or have other barriers for not choosing PB options. Overall, attitudes toward ingredients in the milk and burger categories seem to be influenced by people's understanding (i.e., cognitive considerations) of

Segmentation		AF		LL		LI		PF		CC	
MILK CATEGORY											
Size	N (%)	138 (23%)		95 (16%)		110 (18%)		107 (18%)		150 (25%)	
Factor	Level	Importance,	Utility	Importance,	Utility	Importance,	Utility	Importance,	Utility	Importance,	Utility
Food Ingredient	Plant-based	**58%**	-2.5	9%	-0.1	14%	0.1	**54%**	2.4	7%	-0.1
	Animal-based		2.5		0.1		-0.1		-2.4		0.1
Pack-aging	Recycled plastic	13%	-0.4	11%	-0.2	29%	0.5	20%	-0.9	**60%**	-2.3
	Cardboard cont.		0.4		0.2		-0.5		0.9		2.3
Storage Condition	Refigerated	8%	0.0	27%	-0.9	22%	-0.1	9%	-0.3	14%	-0.4
	Ambient		0.0		0.9		0.1		0.3		0.4
Labels	Organic	21%	-0.3	**52%**	-0.7	**35%**	0.3	17%	-0.1	19%	-0.1
	Fair Trade		-0.7		-1.3		0.0		-0.5		-0.3
	Local		1.0		2.0		-0.4		0.6		0.4
BURGER CATEGORY											
Size	N (%)	142 (24%)		101 (17%)		88 (15%)		201 (34%)		68 (11%)	
Factor	Level	Importance,	Utility	Importance,	Utility	Importance,	Utility	Importance,	Utility	Importance,	Utility
Food Ingredient	Plant-based	**63%**	-3.0	12%	0.2	18%	0.3	**63%**	3.1	10%	0.1
	Animal-based		3.0		-0.2		-0.3		-3.1		-0.1
Pack-aging	Recycled plastic	7%	-0.1	11%	-0.2	17%	-0.1	9%	-0.4	**59%**	-2.4
	Cardboard cont.		0.1		0.2		0.1		0.4		2.4
Storage Condition	Refigerated	9%	0.0	30%	1.0	28%	-0.5	11%	0.4	9%	0.2
	Frozen		0.0		-1.0		0.5		-0.4		-0.2
Labels	Organic	21%	-0.3	**47%**	-0.7	**36%**	0.5	16%	-0.1	22%	-0.4
	Fair Trade		-0.8		-1.1		-0.1		-0.5		-0.5
	Local		1.1		1.8		-0.4		0.6		0.9
COMPARISON OF PRODUCT CATEGORIES											
Shared members		75%		54%		41%		84%		30%	

Fig. 4. Segments of dairy and burger products based on a conjoint study, described by their importance (the highest % of the subgroup is in bold) and utility levels. Abbreviations: AF as "Animal-based food"; LL as "Local label"; LI as "Label importance"; PF as "Plant-based food"; CC as "Cardboard container".

Characteristic	Social	Environment	Economy	Health
MILK CATEGORY				
Plant-based (PB)	0.90*	0.70	0.30	0.60
Animal-based (AB)	-0.90*	-0.70	-0.30	-0.60
Recycled plastic	-0.50	-0.60	-0.10	-0.30
Cardboard	0.50	0.60	0.10	0.30
Refrigerated	-0.30	-0.60	-0.50	-0.70
Ambient	0.30	0.60	0.50	0.70
Organic	0.50	0.10	0.60	-0.20
Fair Trade	0.50	0.10	0.60	-0.20
Local	-0.50	-0.10	-0.60	0.20
BURGER CATEGORY				
Plant-based (PB)	0.90*	0.90*	0.05	0.80
Animal-based (AB)	-0.90*	-0.90*	-0.05	-0.80
Recycled plastic	-0.20	-0.20	-0.67	0.10
Cardboard	0.20	0.20	0.67	-0.10
Refrigerated	0.60	0.60	0.46	-0.30
Frozen	-0.60	-0.60	-0.46	0.30
Organic	0.10	0.10	-0.56	0.70
Fair Trade	-0.10	-0.10	0.10	0.80
Local	-0.20	-0.20	0.15	-0.90*

Fig. 5. Heat map of Spearman's correlation coefficient values (ρ) for sustainability dimensions and product characteristics. Calculated by comparing segments' average utility values (conjoint) and average agreement with sustainability statements (SPDS). Green indicates a positive correlation, red indicates a negative correlation and darker colours represent a stronger correlation. * Significant values ($p < 0.05$).

environmental, social, and health sustainability.

It was also shown that health and environmental dimensions had stronger correlations with the milk category than with the burger category. Thus, while social aspects (e.g. animal welfare and food equity) are strongly associated with PB products for both product categories, environmental and health aspects are more important for burger products than for milk products. From an environmental point of view, the global emission intensity of beef in 2020 was much higher at 30.28 CO2eq/kg, compared to 0.97 CO_2eq/kg for cow's milk (FAOSTAT, 2023). This aligns with the perception that the choice of food ingredients was more crucial for burger products than for milk. The same applies to health factors, as dairy fats show less evidence of increasing cardiovascular disease risk than other animal fats (Duarte et al., 2021; Sendra, 2020). However, the suffering and death of animals per calorie can be much higher for dairy production than for meat (Kolbe, 2018), challenging the view that animal welfare is equally important in the social dimension.

It is important to recognise that participants' habits, including cultural and social expectations (subjective norms), may have affected their choices of sustainable products, even though the study was designed to minimise this effect. The finding that consumers perceived the negative impact of AB food production on sustainability more strongly for burgers than for milk products seemed to be related to their consumption habits. In 2020, Sweden consumed 211 kg of milk per capita compared to 184 kg in Italy, whereas for meat, it was 98 kg and 101 kg, respectively (Ritchie et al., 2023). This may explain why opinions on the sustainability of a particular food ingredient were stronger when the consumption of that product group was higher among Swedish and Italian consumers

Further, the differences between the AF and PF segments were somewhat expected. For example, consumers in the AF segment were more likely to be omnivorous and less likely to purchase PB alternatives, while the opposite was true for the PF segment. Consumers in the AF segment were also more likely to be over 55 year old and men, as older age groups and men tend to prefer AB products (Ipsos, 2018). This highlights an opportunity for educational and marketing strategies targeting older consumers and men, emphasising the environmental, social and health benefits to shift attitudes. Interestingly, AF respondents were more likely to be Swedish, which may reflect a sample bias, as the Swedish group included more omnivorous participants than the Italian group. However, cultural factors could also play a role. The traditional Mediterranean diet in Italy includes cereals and legumes as primary plant-based protein sources, often promoted for their lower environmental impact (Aureli et al., 2023). Italians typically consume more PB proteins due to their strong connection to Mediterranean cuisine, while Swedes consume more AB proteins due to dairy (de Boer et al., 2006). The question is which factor had a greater influence: did consumers develop stronger attitudes toward PB alternatives after recognising the sustainability impacts of AB production (cognitive factors), or were they more influenced by the behaviours of those around them (subjective norms). If it's the former, educational initiatives on the impacts of AB production could enhance the adoption of PB alternatives, whereas for the latter, leveraging social influence and trends might facilitate PB adoption.

Packaging

It was anticipated that cardboard containers would be perceived as the more environmentally sustainable option. Generally, negative views towards plastic packaging have become widespread, also known as "plastic bashing" (Otto et al., 2021). For example, packaging that combines plastic and paper is seen as more sustainable than just plastic (Sokolova et al., 2023), even though mixed packaging can be harder to recycle, since it limits the potential to process the material (Lahl and Zeschmar-Lahl, 2024; Ragaert et al., 2020). After all, it has been suggested that sustainability perception of the packaging material is often based on affective feelings rather than cognitive reasoning (Otto et al., 2021). There was no difference between Italian and Swedish consumers; thus, the perception of cardboard containers as more sustainable was a common tendency across the entire sample. This suggests that the results were likely not influenced by widely accepted practices (subjective norms), such as the prevalent use of plastic, which dominates the global packaging material market (Statista, 2023).

It was not surprising that cardboard containers were linked to the environmental dimension for the milk category (moderate correlation), as cardboard is generally considered to have the lowest environmental impact (Otto et al., 2021; Palfy and Marenčíková, 2021; Steenis et al., 2017). However, the moderate correlation with the social dimension was unexpected, as sustainable packaging usually focuses on environmental and economic factors, with social aspects often overlooked (Lau and Wong, 2024; Lewis et al., 2010). While the exact reason for the association with the social dimension in this study remains unclear (a possibility for future research), it suggests that social considerations still play a role for consumers. Making sustainable packaging more available can provide equal opportunities for people to encourage sustainable choices (Boz et al., 2020; Lewis et al., 2010) as well as policies can guide consumers in making sustainable packaging choices (Lewis et al., 2010). In other words, making sustainable choices more accessible through perceived behavioural control.

Cardboard containers for burger products were moderately linked to the economic aspect, suggesting that consumers may have seen these products as more affordable. Cardboard packaging is sometimes seen as more expensive (Otto et al., 2021). For example, tomato soup packaged in cardboard is considered cheaper than when packaged in plastic (Steenis et al., 2017). However, price perception can vary by product, as the packaging choice for milk was not linked to the economic dimension. For instance, cardboard and plastic packaging for carrots were viewed as similarly priced (Nørgaard Olesen and Giacalone, 2018). Other sustainability dimensions were not associated with packaging material in the burger category. Hence, consumers may have considered potential issues with cardboard containers, such as food safety, shelf-life concerns, and an increased risk of food waste. It is also possible that the decisions were influenced by habits (norms), rather than purely cognitive or affective attitudes. Baptista and Schifferstein (2023) discussed that conventional milk products are often packaged in plastic, while other alternatives (e.g. organic or PB) tend to use cardboard, and most meat products come in plastic trays. Since cardboard is less common than plastic for burger packaging, this could have influenced consumers' decisions.

The previously observed tendency to base packaging opinions on affective feelings (Otto et al., 2021) might have caused the high variation in views across product categories. In particular, CC members showed the greatest difference, with only 30 % of members shared in both the milk and burger categories. Additionally, sustainability concerns related to AB products were less pronounced among CC consumers, who not only demonstrated a higher frequency of purchasing AB dairy and meat products (significant in the burger category) but also displayed less variation in perception of specific food ingredients. Since packaging material serves as a visual signal, it could be a primary cue influencing the CC segment's decisions in the CBC task. Seo et al. (2016) found that the level of packaging significantly impacted the willingness to purchase sustainable products, highlighting that packaging often outweighs the importance of ingredients. While the current study focused on sustainability perceptions rather than purchasing decisions, it is plausible that perceptions of sustainability are similarly influenced by packaging. For example, these consumers may be less willing to purchase products with exaggerated packaging, even with eco-friendly food ingredients (Seo et al., 2016). In short, how people understand the connection (cognitive associations) between packaging and sustainability may have a greater influence than their perception of the actual food ingredients. For the milk category, however, CC respondents were significantly more likely to be Italian. There may be a growing

trend in cardboard packaging in Italy (suggesting subjective norms); however, as published information is limited, further studies should be conducted. In conclusion, using cardboard containers as packaging generally appears to be an effective way to promote sustainable choices, appealing to a broad group of consumers — regardless of whether their primary focus on sustainability is related to food ingredients or packaging design.

Storage condition

Storing milk products at ambient temperature showed a moderate link with economic, health, and environmental dimensions. This may be because the ambient temperature condition was seen as more affordable (Merlino et al., 2022), safer due to sterilisation by UHT (Ultra High Temperature) treatment, and easier to store and transport (requiring less energy) compared to refrigerated milk. However, sustainability isn't the only factor affecting people's views on storage conditions. Heat treatment can alter the sensory characteristics of products. UHT milk has more "cooked" flavours, which some people may or may not prefer (Coolbear et al., 2022), whereas heat treatment can enhance nuttiness in nut-based drinks or earthiness in rice-based drinks (Vaikma et al., 2021).

Refrigerated burgers were positively linked with social and environmental dimensions. The exact reasons for this need more investigation, but it might be due to cultural habits (including subjective norms) or the idea of a shorter, local supply chain (related to segment LL) is better than for frozen burgers. Environmentally, frozen food often uses more energy because of energy-intensive storage and transport needs (Ladha-Sabur et al., 2019; Zanoni and Zavanella, 2012). However, energy efficiency is complicated; frozen food can also lead to less waste because it lasts longer and can be portioned easily, reducing leftovers. Despite this, frozen meat is often seen as less fresh and of lower quality, with people not aware of its sensory and nutritional benefits (Hati et al., 2021; Zhang et al., 2023). This trend is also seen with fruits and vegetables, where fresh produce is considered healthier (Lusk, 2019), even though frozen options may retain nutrients better (Grover and Negi, 2023). Given the weak link with health aspects, it seems consumers did not focus on these factors.

Overall, the way milk is stored didn't seem to be a major factor for sustainability. People's opinions were likely influenced more by specific market trends (Bousbia et al., 2017; Ramírez et al., 2006). In Italy, more UHT milk is produced and consumed than fresh pasteurised milk (Merlino et al., 2020, 2022), yet there is interest in both (Merlino et al., 2020; Rysstad and Kolstad, 2006). In Sweden, however, the market for UHT milk is rather limited (Karlsson et al., 2019; Rysstad and Kolstad, 2006), which may explain why Italian respondents found ambient storage more important than Swedish. When it comes to burgers, Italians generally don't choose frozen meat, which is consistent with other studies (Magdelaine et al., 2008; Szendrő et al., 2020). In Sweden, there wasn't a clear preference for how burgers should be stored, but Swedes are becoming more open to freezing. For example, frozen bread is becoming an increasingly popular method for Swedes to reduce food waste (Furbeck and Sjödin, 2017). When looking at different consumer groups, how milk and burgers are stored wasn't a major factor in their views on sustainability. This means storage conditions weren't as important in decision-making compared to things like food ingredients or packaging. Storage conditions, while important, may not need to be a central focus in sustainability communication.

Labels

Label associations with specific dimensions were varied for the milk and burger category. This confirms the previous discussion that sustainability perception could have been more diverse and influenced by various other aspects. Also, it is important to note that the interaction of various labels can affect the perception of a single label, which was not tested in the current study. For example, if organic apples are preferred, then these consumers also often prefer local apples, but not the other way around (Denver and Jensen, 2014). On the other hand, consumers may be more willing to purchase Fair Trade apples if it also is a local product (Onozaka and McFadden, 2011). Positive correlations with the health dimension in the burger category further suggested that there could have been a health halo effect with organic and Fair Trade labels, as previous research implies (Berry and Romero, 2021; Nadricka et al., 2020). Interestingly, while the organic label was moderately positively associated with the economic dimension for milk, and moderately negatively for burger, it may suggest that milk is generally more affordable than meat. While the price of raw milk (paid to milk producers) in the EU was on average €44/100 kg in August 2023, the price of beef (paid to farmers) was €410/100 kg (European Commission, 2023a). As organic food is more expensive than non-organic food, consumers are often less interested in purchasing (Bernabéu et al., 2023; Katt and Meixner, 2020). However, they may be willing to pay up to a 60 % premium for organic products (Ribeiro, 2023), depending on many factors such as the quality, locality, health awareness and environmental concern (Katt and Meixner, 2020). Furthermore, the proportion of households willing to pay for organic milk may be much higher than for organic meat (Millock and Hansen, 2002).

This study found that the local label was the most important indicator of sustainability, similar to other studies where location was prioritised over organic and Fair Trade claims (Onozaka and McFadden, 2011), although it was tested in terms of purchasing. At the same time, it was surprising to find that the strongest correlations with sustainability dimensions were often negative. In this experiment, "local" was a non-certified, non-standardised label. It can be associated with various proximity aspects such as geographical (e.g. distance), access (e.g. ease of access), functional (e.g. easily findable), process (e.g. freshness), price (e.g. quality-to-price ratio), identity (values, e.g. sustainability), relational (e.g. trust), cultural (e.g. tradition), and technological proximity (e.g. technological experience) (Chicoine and Rodier, 2022). Therefore, while consumers saw the local label as the most important sign of sustainability, its actual connection to sustainability was not always clear. In the real world, the large number of sustainability labels and the lack of regulation often lead to consumer confusion and distrust (Rossi and Rivetti, 2023). Given this confusion, it can be suggested that if correlations with sustainability were negative, consumer opinions might have been more influenced by lack of regulations (perception of control) rather than specific sustainability aspects.

Fair Trade was seen as the least important label for sustainability, which may indicate that people don't associate it as strongly with sustainability as other labels. Fair Trade aims to address inequality among producers in developing countries based on ethical standards (Ribeiro-Duthie et al., 2021) and is often associated with social, environmental (Eldesouky et al., 2020; Konuk, 2019), and health (Berry and Romero, 2021; Nadricka et al., 2020) benefits. However, other studies have highlighted various barriers to choosing Fair Trade products. For example, there might have been less trust in the label, lack of awareness, association with price (Bürgin and Wilken, 2022; Konuk, 2019; Sirieix et al., 2013) or long-distance production. Lack of trust and concerns about long-distance production may lower positive attitudes toward Fair Trade products, while factors like higher prices and low awareness could reduce consumers' sense of control (perceived behavioural control). When combined, these factors may reduce people's likelihood of choosing Fair Trade products, even if they recognise the potential benefits.

The LL segment consumers prioritised the localness of AB products for sustainability. PB alternatives are mostly imported or made from imported main ingredients (Estell et al., 2021; Luiz Morais-da-Silva et al., 2022). Thus, local PB alternatives are less often available, which may have been the reason why consumers in the LL segment were more likely AB product purchasers. This suggests that PB production could benefit from shifting toward more local production. However, future studies could further investigate how the origin of PB alternatives

matters for consumers. Another link between the preference for local products and the purchase of AB products may be related to cultural background. As local products are often associated with local identity (subjective norms), that is, culture and tradition (Chicoine and Rodier, 2022), it is possible that the preference for AB products is also linked to a sense of traditionality for these consumers. Given that the PB alternative market has been rapidly increasing over the last 15 years (Aschemann-Witzel et al., 2021), these alternatives are not yet familiar to everyone. Increasing consumer awareness through clear marketing campaigns and product trials in shops and restaurants is a viable approach to familiarise people with PB alternatives and encourage their adoption.

The LL segment consumers prioritised the local origin of AB products for sustainability. PB alternatives are mostly imported or made from imported main ingredients. Thus, local PB alternatives are less often available, which may have been the reason why consumers in the LL segment were more likely to purchase AB products. This suggests that PB production could benefit from shifting toward more local production. However, future studies could further investigate how the origin of PB alternatives matters for consumers. Another link between the preference for local products and the purchase of AB products may be related to cultural background. As local products are often associated with local identity (culture and tradition), it is possible that the preference for AB products is also linked to a sense of tradition for these consumers. Given that the PB alternative market has been rapidly increasing over the last 15 years, these alternatives are not yet familiar to everyone. Increasing consumer awareness through clear marketing campaigns and product trials in shops and restaurants is a viable approach to familiarise people with PB alternatives and encourage their adoption.

LI consumers showed less similarity in the milk and burger categories (41 % members shared) compared to LL consumers (54 % members shared). This indicates a wider range of opinions on the labelling issue among LI consumers. As mentioned earlier, sustainability labels are often unregulated (Rossi and Rivetti, 2023), and labels used worldwide can vary significantly. Consequently, LI group may have experienced greater confusion and/or had a more varied understanding of the labels, although they generally prioritised the label in the CBC task. Even with nutritional labels, where labelling regulations vary, consumers can easily misinterpret the information if the label format differs from what they are accustomed to (Kim et al., 2021; Mayhew et al., 2016). Consumer education and label standardisation could effectively address these issues in the LI segment. Although LI segment's utility scores differences were rather low, it was more likely that they were perceiving organic as more sustainable. In the milk category, LI consumers were significantly more likely from Italy, which should be further investigated as the results may vary in context. While it was previously shown organic was the least important milk characteristic for Italian consumers when making a product choice (Tabacco et al., 2021), a discrete choice experiment with Italian consumers suggested that organic milk is preferred when accompanied by additional information (Scozzafava et al., 2020). This highlights that the way consumers comprehend sustainability shapes their perception of what constitutes a sustainable product. For the burger category, LI consumers purchased significantly fewer PB meat alternatives. An earlier study by Zanoli et al. (2013) showed that Italian consumers valued organic beef more than conventional and genetically modified ingredient-fed beef. Therefore, promoting the benefits of organic meat and dairy products, as well as PB alternatives, could be particularly beneficial.

Limitations and future research

The sample was limited to participants from Sweden and Italy, so the results may not be generalisable to other countries. A review by Bangsa and Schlegelmilch (2020) found that sustainability priorities in product attributes vary by country, with the environmental dimension often being more important in developing countries and the social dimension in developed countries. It would be interesting to conduct a study in various cultures to further explore the cross-cultural differences in sustainability perception. Additionally, a more detailed breakdown of different dietary habits, such as distinguishing between vegans, vegetarians, and flexitarians, could have provided more insights into diet groups. The study may also have sample bias, as the AF segment included a higher proportion of Swedish respondents, who tended to be more omnivores compared to the Italian respondents.

The packaging designs used in this study were conceptual. Other packaging designs might lead to different ideas about sustainability. For example, glass (which was not tested in this study) is often seen as the most sustainable by consumers (Dlamini et al., 2024; Otto et al., 2021), even though its sustainability is sometimes overestimated due to higher GHGE emissions and energy use during production (Otto et al., 2021). Another question is whether differences in packaging design (e.g. colours, photos and icons) might have influenced decisions about milk and burgers, since aesthetics can influence perception of a product (Malešević and Stančić, 2021). For example, Nørgaard Olesen and Giacalone (2018) showed that packaging type is a key factor in consumers' quality perception of carrots, regardless of other aspects such as colour or being organic. However, this part is not fully explored in our research, as the main focus was not to test different packaging designs and their impact on consumer views on sustainability.

Some of the factors tested could be further explored. For instance, whether the limited availability of local PB alternatives makes people think that locality is less important for sustainability. Specific dimensional differences between product categories can also be further examined, for example, how the economic dimension links with cardboard packaging for some products but not for others. Moreover, this study did not explore how different factors influencing sustainability might work together. Interaction effects might be significant (Almli and Næs, 2018), for instance, perceived sustainability of PB ingredients might vary depending on the type of packaging used. Future research examining these combined effects could provide a clearer understanding of consumers' views on sustainability.

Individuals may express views they believe are more socially acceptable rather than their actual opinions, a phenomenon referred to as social desirability bias (Cerri et al., 2019). This study used self-reported survey data, which could be influenced by social desirability bias in sustainability research (Cerri et al., 2019). This can lead to inaccurate data, as respondents might misrepresent their actual views. As a result, the findings might show an idealised version of consumer attitudes instead of their real priorities. The CBC study, which attempts to mimic real-life choice environment, could have reduced this bias (Horiuchi et al., 2022). However, there are more choices and factors involved in real life. For example, price, one of the most important purchase drivers (Fox et al., 2021; Seubelt et al., 2022; Stewart-Knox et al., 2024), was intentionally excluded because this study did not focus on simulating a buying scenario. Similarly, taste is often a key factor in food choices (Dana et al., 2021; Tepper and Barbarossa, 2020), but sustainability perceptions can also influence how people perceive taste (Bschaden et al., 2022). Thus, this study does not cover all the factors that shape how consumers view sustainability, and further research is needed.

Conclusions

Sustainability is an increasingly important issue, but people's thoughts about it don't always match their actions. Therefore, it's crucial to study both perspectives. Our research looked at how people perceive sustainability in milk and burger products and their PB alternatives, considering aspects like food ingredients, packaging, storage, and labels. This study looks at how consumers see sustainability in different ways, showing its complex nature. This multidimensional approach can also be applied in other areas for future research.

The findings confirmed that people have different views on what

makes products sustainable, as suggested in earlier studies. For example, packaging was the second most important factor for milk category but was the least important for burgers. The study also found that the food ingredients were the most notable sustainability factor for both milk and burgers, indicating how crucial sustainable ingredients are in consumer choices. Interestingly, people considered PB ingredients more in burgers than in milk, indicating a greater concern for the sustainability impact of AB burgers compared to AB milk. This indicates that people's views on sustainability vary widely based on the kind of product they are looking at.

It was also evident in the milk and burger categories that cardboard containers and local labelling were perceived as more sustainable than recycled plastic or other labels. However, local labelling was not clearly linked with specific sustainability dimensions, indicating that other factors might influence consumer opinions. Cardboard containers, on the other hand, were mainly connected with the environmental dimension, but also had ties to economic and social aspects. Overall, storage conditions were viewed as the least important factor in determining sustainability in both milk and burger products, suggesting that consumers' evaluations of sustainability are more influenced by availability and habits rather than by active consideration of storage factors. Lastly, it was clear that not all sustainability features are equally important for people across different product categories; for example, some consumers may prioritise storage conditions for sustainability, while others may not consider them at all.

Managerial and practical implications

From a managerial perspective, the findings of this study provide key insights for industry professionals and educational campaigns, helping to bridge the gap between consumer perceptions and sustainability practices. Bridging this gap is particularly relevant for individuals who have sustainability perceptions but do not fully translate them into their actions. For those who lack sustainability perceptions altogether, the challenge lies in raising awareness. For instance, food ingredients were the most important sustainability characteristic for both milk and burger products, suggesting that emphasising ingredient sustainability in communication strategies can effectively engage sustainably conscious consumers and educate sceptical ones. Further, PB ingredients were more strongly linked to sustainability in burgers than in milk, indicating the need to tailor communications to specific product categories to better align with consumer perceptions. For AB products, often preferred by older, men, omnivorous consumers (segment AF), sustainability messaging should address their preferences with targeted approaches highlighting health, environmental, and social dimensions, as they prioritised these dimensions significantly less.

From a practical perspective, it's important to understand how consumers view sustainability to encourage more sustainable choices. Businesses should refine their products and communications to match what consumers are looking for, by focusing on key features like food ingredients and packaging. For example, health-related sustainability messages may be more effective for burgers than for milk products. Clear and detailed information about how product features contribute to sustainability can help create positive attitudes and informed decisions. Further, cardboard containers and local labelling were seen as more sustainable compared to recycled plastic and other labels. Businesses should clearly highlight the benefits of local labelling and promote cardboard packaging to consumers who value environmental, economic, and social aspects of sustainability.

Overall, people value different sustainability features depending on the product. Businesses can leverage segmentation strategies to match their messages with what specific consumers prefer. For example, even though storage conditions were generally seen as less important for sustainability, some consumers considered them important. Sustainability-focused product lines could highlight advanced storage features, while mainstream products might communicate ingredient and packaging sustainability, which are easier for most consumers to understand.

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Ethical statement

This study was carried out following the Principles of Academic Ethics by Tallinn University of Technology (TalTech, 2017), which addresses ensuring the safety of research and data processing. This study does not include collecting sensitive personal data, as the survey only includes questions about sustainability perception and demographical characteristics. Regardless, responsible data management was implemented to prevent participant identification and ensure confidentiality, according to the General Data Protection Regulation (GDPR). Participants were also informed of the general purpose of the study and provided informed consent to participate in this study. All the participants were made aware that participation was voluntary, enabling them to withdraw from the study at any time.

CRediT authorship contribution statement

Helen Vaikma: Writing – original draft, Visualization, Validation, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Martin Kern:** Writing – review & editing, Investigation, Formal analysis, Data curation. **William Harwood:** Writing – review & editing, Methodology. **Valérie L. Almli:** Writing – review & editing, Supervision, Methodology.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.fufo.2025.100635.

Data availability

Data will be made available on request.

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Appendix 5

Table A5.1
Structure of the final 22-item Sustainability Dimensions Perception Scale (SDPS). Compiled based on Appendix A5 in Article III.

Item	Statement
	SOCIAL DIMENSION
S1	I think that knowledge of sustainable consumption and production must be passed on to future generations.
S2	I think that fair trade products should be preferred to improve social justice for growing countries.
S3	I think that the surrounding food culture must promote a sustainable diet.
S4	I think that humankind's habits should meet current needs without compromising the opportunities of future generations.
S5	I think that policies must promote the production and consumption of sustainable products.
S6	I think that it is important to safeguard the working conditions of the people involved in the workforce.
S7	I think that all people must have equal opportunities regardless of their demographic background (age, sex, disability, race, ethnicity, origin, religion or economic or other status).
	ENVIRONMENTAL DIMENSION
EN1	I think that locally grown and produced food should be preferred because it is better for the environment.
EN2	I think that excessively packaged products should be avoided.
EN3	I think that eating seasonal fruits and vegetables has less stressful environmental impact.
EN4	I think that foods that have undergone as little processing as possible during production are more environmentally friendly.
EN5	I think that waste should be reduced by using reusable containers instead of disposable packaging.

	ECONOMIC DIMENSION
EC1	I think that it is important that different actors in the supply chain collaborate in the production process.
EC2	I think that economic productivity should be increased through diversification, technological development and innovation.
EC3	I think that it is important to support decent job creation through promotion of entrepreneurship, creativity and innovation.
EC4	I think that it is important to strengthen the capacity of domestic financial institutions to widen access to financial services (incl. banking, insurance) for all people.
EC5	I think that increasing resource efficiency in consumption and production (e.g. use of 'non-edible' parts of plants/animals or non-standard shaped/sized vegetables) is economically important.
	HEALTH DIMENSION
H1	I think that foods that have undergone as little processing as possible during production have higher nutritional value.
H2	I think that potential health benefits of the product are important when making the purchasing decision.
H3	I think that seasonal fruits and vegetables should be preferred because they are more nutritional and beneficial for the health.
H4	I think that local food should be preferred because it has more nutritional value than imported food.
H5	I think that products without any additives (e.g. food, cosmetics) should be preferred because of health concerns.

Curriculum vitae

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2013–2016	Tallinn University of Technology, Department of Food Processing, Faculty of Chemistry and Biotechnology, Food technology and Product Development – BSc
2010–2013	Tallinn Nõmme Upper Secondary School – science class (silver medal)

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2017–…	Toidu- ja Fermentatsioonitehnoloogia Arenduskeskus, teadur

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Research scholarships

2024–	Kristjan Jaak Scholarship for short study visits (The Education and Youth Board, Estonia), presentation at the EuroSense 2024 conference in Ireland
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2022–	Kristjan Jaak Scholarship for short study visits (The Education and Youth Board, Estonia), presentation at the EuroSense 2022 conference in Finland
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2020–	Dora Plus T1.1 short-term study mobility scholarship (The Archimedes Foundation, Estonia) – trip cancelled due to COVID restrictions, scholarship waived

Selection of other publications

Jakobson, K.; Kaleda, A.; Adra, K.; Tammik, M.-L.; **Vaikma, H.**; Kriščiunaite, T.; Vilu, R.; (2023). Techno-Functional and Sensory Characterization of Commercial Plant Protein Powders. Foods, 12 (14), 2805. DOI: 10.3390/foods12142805. (ETIS 1.1)

Part, N.; Kazantseva, J.; Rosenvald, S.; Kallastu, A.; **Vaikma, H.**; Kriščiunaite, T.; Pismennõi, D.; Viiard, E. (2023). Microbiological, chemical, and sensorial characterisation of commercially available plant-based yoghurt alternatives. Future Foods, 7, #100212. DOI: 10.1016/j.fufo.2022.100212. (ETIS 1.1)

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Andreson, M.; Kazantseva, J.; Kuldjärv, R.; Malv, E.; **Vaikma, H.**; Kaleda, A.; Kütt, M.-L.; Vilu, R. (2022). Characterisation of chemical, microbial and sensory profiles of commercial kombuchas. International Journal of Food Microbiology, 373, 109715. DOI: 10.1016/j.ijfoodmicro.2022.109715. (ETIS 1.1)

Jakobson, K., Kriščiunaite, T., Kaleda, A., **Vaikma, H.**, Vilu, R. (2022). Characterization of techno-functional and sensory properties of commercial plant-based protein powders for meat and dairy alternatives - Oral conference presentation. BOOK OF ABSTRACTS: 27th Congress of The Nordic Association of Agricultural Sciences, Selfoss, Iceland, 27-29 September 2022. Publicon, 48–48. (ETIS 1.1)

De Angelis, D.; Kaleda, A.; Pasqualone, A.; **Vaikma, H.**; Squeo, G.; Caponio, F.; Summo, C. (2021). How to Balance the Yield and Protein Content of Air-classified Pulse Flour: the Influence of the Restriction Valve. Chemical Engineering Transactions, 87, 241−246. DOI: 10.3303/CET2187041. (ETIS 1.1)

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De Angelis, D.; Kaleda, A.; Pasqualone, A.; **Vaikma, H.**; Tamm, M.; Tammik, M.-L.; Squeo, G.; Summo, C. (2020). Physicochemical and Sensorial Evaluation of Meat Analogues Produced from Dry-Fractionated Pea and Oat Proteins. Foods, 9 (12), #1754. DOI: 10.3390/foods9121754. (ETIS 1.1)

Supervised dissertations

Metsoja, G., Master's Degree, 2023, (sup) **Vaikma, H.**; Bljahhina, A., Kibedust põhjustavate ühendite sensoorne ja instrumentaalne analüüs kaeras ja hernes (Sensory and instrumental analysis of compounds causing bitterness in oat and pea), Tallinn University of Technology, School of Science, Department of Chemistry and Biotechnology; AS TFTAK

Koemets, K., Master's Degree, 2023, (sup) **Vaikma, H.**; Arvola, R., Liha taimsete alternatiivide ja jätkusuutlikkuse hoiakud tarbijate seas (Consumer attitudes towards plant-based meat alternatives and sustainability), Tallinn University of Technology, School of Business and Governance, Department of Business Administration

Birk, P., Master's Degree, 2022, (sup) **Vaikma, H.**; Hartšenko, J., Eeliskombinatsiooni analüüs tarbijate eelistuste väljaselgitamiseks tomatipüreede näitel (Conjoint analysis of consumer preferences for tomato purees), Tallinn University of Technology School of Business and Governance, Department of Business Administration

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2020–	Dora Pluss T1.1 lühiajalise õpirände stipendium (SA Archimedes, Eesti), reis tühistatud COVID piirangute tõttu, stipendiumist loobutud

Valik teisi publikatsioone

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